PRACTICAL TREATISE

ON

CASTING AND FOUNDING.

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INCLUDING

DESCRIPTIONS OF THE MODERN MACHINERY EMPLOYED IN THE ART.

BY

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THIRD EDITION.

LONDON:

E. & F. N. SPON, 16, CHARING CROSS.

NEW YORK:

44, MURRAY STREET.

1882.

INTRODUCTION.

Until comparatively modern times the manufacture of iron was confined to wrought work, fusible cast-iron was an unknown material, and its valuable properties when in a molten liquid state were little thought of. In the reign of Queen Elizabeth cast-iron was a comparative novelty; and works in that material, produced as recently as the commencement of the present century, show that the ironfounder's art had made but little progress. Within the last fifty years, however, gigantic strides have been taken, and cast-iron is now applied to a multitude of purposes, the articles made from it ranging in size from a half-pint saucepan up to an anvil block, which takes months to cool down after it has been cast.

There have been numerous causes at work to account for the rapid development of this important branch of the world's industry. First, of course, comes the utilization of steam, which, by affording means of transport, admitted of the collection of iron ore, flux, and fuel from widely separated localities. Steam also gave a great incentive to the use of machinery, in the construction of which cast-iron was introduced.

Improvements in blast engines, a thorough knowledge of the chemical properties of the various ores, and the nature of the fuel best fitted to use with them, have resulted in the production of a certain uniform quality of cast-iron, possessing very great fluidity.

To keep pace with the ever-increasing demand for works in cast-iron, the greatest ingenuity has been used in devising furnaces and machinery and ingenious workshop appliances, for dealing with larger quantities of molten metal; whilst much attention has also been devoted to improvements in pattern-making, moulding in loam and sand, cores, and the like, which latter branches are,

however, only to be thoroughly mastered by actual experience in the shops, combined with a good general knowledge of the nature and chemical properties of various materials, and the laws of heat and pneumatics.

Theoretical knowledge is of no service to the founder without experience, and the exercise of the greatest care and watchfulness at every step; as the peculiarity of the art is, that if only one small point is overlooked in the numerous processes leading up to the final operation of casting, the omission will probably not be discovered until it cannot be rectified, or, in other words, until the casting is found to be a "waster," only fit to be broken up, and remelted at a great expense, and the whole operation has to be repeated.

Such failures are by no means uncommon, even in the shops of leading firms, and it need scarcely be said that the profit on the manufacture of say an engine is very materially reduced if several cylinders have to be cast before a satisfactory one is obtained.

It is not within the scope of the present work to describe the extraction of metals from their ores; the founder's business is to deal with the metals themselves, and by his art to change pigs and ingots into the useful and ornamental appliances met with in every direction in all civilized communities.

Numerous valuable works have been written on the reduction of ores, the theory of the blast furnace, chemical considerations affecting the treatment and manufacture of iron and steel; copper, tin, and silver smelting, are all fully described, but moulding and founding appear to have been comparatively neglected. Small treatises on different branches of the subject undoubtedly exist, and able articles have from time to time appeared in the columns of the scientific periodicals, but the labour of searching for and comparing such information is very great, and only possible of performance in cities, where large libraries of reference are accessible.

The object of this work has been to collect in one volume every subject on which it is probable that a founder will require infor-

mation, in whatever material he deals with, and to place that information before him clearly, concisely, and in as practical a manner as the subject will allow. Consequently little space has been devoted either to chemical considerations or to abstruse formulæ, and where it has been found necessary to point out the chemical effects of certain processes, this has been done with the utmost simplicity consistent with accuracy. The writer has often felt the want of such a work himself, and if others had taken upon themselves the task, the present work would never have been written.

It has been truly said, that every engineer should have a good knowledge of chemistry, but the time has not yet arrived for the attainment of that desirable object, nor can it be expected that the founder, an eminently practical man, should be thoroughly acquainted with the great study of theoretical chemistry applied to metallurgical processes.

In so complicated an art, the experience of any one man can be but limited to his own circle of observation, and the writer desires therefore to acknowledge the aid he has received from many personal friends; where other information was required it has been obtained from the best authorities in their several branches, the works of Dr. Percy, Robert Mallet, F.R.S., Dr. Siemens, F.R.S., Kohn, and numerous French and Belgian authors have been consulted, and to these gentlemen are due our best thanks.

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FOUNDING AND CASTING.

CHAPTER I.

PIG IRON; ITS CHARACTERISTICS AND MIXTURES.

THE curiosities of the iron manufacture are numerous and interesting, and several of them are at present unaccounted for by the greatest chemical authorities. Commencing with pig iron, the remarkable changes which are effected in its qualities by slightly different treatment are of the utmost importance and utility.

Such are the conversion of pig iron into steel direct, and by the Bessemer process. The power of obtaining from the same cast iron either a soft, flexible, or elastic steel, or one so hard and brittle that nothing softer than corundum or a diamond will cut into it for any length of time; or by merely altering the rapidity of the cooling of the cast iron from its liquid state, to form either hard white chilled castings, or soft grey ones, which can be turned and bored almost as easily as brass.

Pig iron is the form in which cast iron appears when delivered from the smelter, consisting of rough oblong blocks of the metal which have been run direct from the smelting furnace into open moulds.

Cast iron is a granular and crystalline compound of iron and carbon, more or less mixed with uncombined carbon in the form of graphite, but never contains more than 5 per cent. It is harder than pure iron, more brittle, and not so tough, and is obtained by the direct reduction of iron ores in the blast furnace. The modes of combination of the carbon with the metal, as well as the nature and proportion of foreign matters, such as silicon, alumina, sulphur,

phosphorus, and manganese, determine the infinitely varying qualities relating to its colour, degree of fusibility, hardness, tenacity, and so on.

In practice the different varieties of cast iron when in the pig, that is, as they are sent from the smelting furnace, are distinguished by the colour and general appearance shown by newly broken surfaces; these exhibit every variation from dark grey to dead hard white.

All cast irons are not available for foundry purposes; those preferred are irons which become sufficiently fluid upon fusion to fill every part of the moulds into which they are poured, which shrink but slightly upon cooling, which, once in a solid state, admit of easy manipulation, and, whilst satisfying these conditions, possess sufficient strength for the purpose to which they are to be applied. These different qualities are found combined in a higher degree in grey cast iron than in white irons, and the former are therefore most generally used for foundry work.

Grey iron merges into white iron by imperceptible degrees, and in some irons the two are clearly developed in the fracture of one and the same pig; it is then called *mottled* iron, and this is frequently of great strength. Some seven or eight classes may be found running from clear white at the one extreme to dense grey at the other, and each class is commercially recognized by a distinctive number, No. 8 being the whitest, 5 the mottled, and the lower numbers including the grey varieties. But three kinds were at one time classified. In recent years, however, the larger number given above has been almost invariably adopted.

In white cast iron the greater part of the carbon is present in the form of a chemical combination, carbide of iron, whilst in grey cast iron the carbon is mechanically interspersed in small black specks amongst the lighter coloured particles of metal, the fracture being of a dark grey colour, and being of a granular or scaly crystalline character. Grey cast iron is much softer and tougher than white iron, and may be filed, or turned; whilst white iron is very brittle, and can neither be turned in a lathe nor filed.

These qualities may be altered to a certain extent, as by casting grey iron in thick iron moulds, or chills, it becomes almost as hard as steel; but this change takes place only at the surface, the inside

of the casting still retaining its grey colour. If it is desired to soften a casting which is too hard to be turned or bored, this can be done by heating the casting for several hours in a mixture of bone-ash, and coal-dust, or in common sand, and allowing it to cool slowly whilst still imbedded in these bad heat-conducting materials.

Grey cast iron requires a higher degree of heat before it commences to fuse, but becomes very liquid at a sufficiently high temperature, so as easily to be run into moulds.

White cast iron is not so well adapted for casting, as it does not flow well; it is rather pasty in consistence, and scintillates as it flows from the furnace to a much greater extent than grey iron.

White cast iron is silvery white, either granular or crystalline, difficult to melt, brittle, and excessively hard.

This quality of iron is obtained by using a low temperature and a small quantity of fuel in the blast furnace. It is a homogeneous chemical compound of iron with from 2 to 4 per cent. of carbon, and is well suited for forge purposes, to which it is generally applied.

Granular cast iron can be converted into grey cast iron by fusion and slowly cooling; whilst grey cast iron can be converted into granular white cast iron by fusion and suddenly cooling.

Crystalline white cast iron is harder and more brittle than the granular, and is not capable of being converted into grey cast iron. This variety is too brittle for use in machinery.

The general composition of the three principal varieties of cast iron is shown by the columns marked F G H in the following table; while in column A is indicated that of the South Wales cinder pig; B, common white pig from the same locality; C, mottled iron made with charcoal and cold blast; D, Dowlais No. 3 best mine pig; and E, Cleveland No. 2 foundry pig.

Grey cast iron contains about 1 per cent. or less of carbon in chemical combination with the iron, and from 1 to 4 per cent. of carbon in the state of graphite in mechanical mixture. The larger the proportion of graphite, the weaker and more pliable is the iron.

No. 1 contains the largest proportion of graphite; it is distinguished in appearance by great smoothness on the surface of the

pig, and is the most easily fusible, produces the finest and most accurate castings, but is deficient in hardness and strength, in which it is inferior to Nos. 2 and 3.

It is indeed charged with carbon to excess, and, when turned, free carbon may be observed flying off like powder. The crystals are large, extending over the entire fractured surface, which shows a characteristic blue-grey colour and coarse grain. When broken, the pig does not ring, but falls asunder with a dull leaden sound, and it usually breaks very evenly, showing but little tenacity. When fluid it is marked by a notable absence of either sparks or splashes. The surface is dark and sluggish, and as it cools it becomes covered with a thick scum, which is a source of much waste. Used very hot, as when melted in a crucible and air furnace, it is so fluid that it will run into the finest and most delicate moulds. This property, as already remarked, peculiarly adapts No. 1 foundry pig for the purpose of small thin and ornamental castings, and anything that requires a minute adaptation of the metal to the mould. No. 1 is not often employed by itself, but commonly as an admixture with scrap.

TABLE I.

<table>
<tr><th></th><th>A
Grey Cinder Pig.</th><th>B
Common White Pig.</th><th>C
Mottled Iron.</th><th>D
Best Mine Pig.</th><th>E
Foundry Pig.</th><th>F
Grey.</th><th>G
Mottled.</th><th>H
White.</th></tr>
<tr><td>Iron .. .. ..</td><td>93·55</td><td>95·27</td><td>93·29</td><td>94·56</td><td>93·53</td><td>90·24</td><td>89·39</td><td>89·86</td></tr>
<tr><td>Combined Carbon</td><td rowspan="2">2·80</td><td rowspan="2">2·42</td><td>2·78</td><td>0·04</td><td>..</td><td>1·82</td><td>1·79</td><td>2·46</td></tr>
<tr><td>Graphite .. ..</td><td>1·99</td><td>3·10</td><td>3·44</td><td>2·64</td><td>1·11</td><td>0·87</td></tr>
<tr><td>Silicon .. .. ..</td><td>1·85</td><td>0·36</td><td>0·71</td><td>2·16</td><td>1·13</td><td>3·06</td><td>2·17</td><td>1·12</td></tr>
<tr><td>Sulphur .. ..</td><td>0·14</td><td>0·87</td><td>trace</td><td>0·11</td><td>0·03</td><td>1·14</td><td>1·48</td><td>2·52</td></tr>
<tr><td>Phosphorus .. ..</td><td>1·66</td><td>1·08</td><td>1·23</td><td>0·63</td><td>1·24</td><td>0·93</td><td>1·17</td><td>0·91</td></tr>
<tr><td>Manganese .. ..</td><td>..</td><td>..</td><td>..</td><td>0·50</td><td>0·43</td><td>0·83</td><td>0·60</td><td>2·72</td></tr>
</table>

No. 2, which is lighter in shade than No. 1, is finer in grain, not so soft, it is not so fluid when melted, nor the skin of the pig so smooth. Being closer grained and more regular in the fracture, it is more tenacious, and, while capable of being easily turned and polished, being harder and stronger than No. 1, it is preferred for

strong ornamental castings. Melted, it is seen to be of a clear reddish white colour, splashing little when poured into the ladle. There is a scum and a sluggish flow, but not to the same extent as with No. 1. When being run into the mould, it breaks over the edge of the ladle in large sheets, leaving behind them long narrow lines running from side to side. As the iron cools, these lines open in various directions until the surface is in lively motion, lines intersecting each other in every direction. This activity continues until the surface becomes stiff or pasty, but, on removing this covering, these lines are again seen flitting over the surface.

No. 3 is the most extensively used foundry iron, owing to its being a medium between the extremes, which can therefore be used for a variety of purposes. It has less carbon than the other two kinds, and possesses less fluidity when melted; it is also more minutely grained, and smoother in the fracture than No. 2. The broken surface shows a slightly mottled appearance at the margin, while at the centre there is a regular arrangement of smaller crystals comparatively compact and dense. As it flows into the ladles there is a display of sparks flying in various directions, and an absence of scum, the surface being clean. Figures are slightly visible at surface, but are small, and pass off entirely as the metal cools. It possesses a greater degree of toughness, as well as hardness, and turns out strong, durable castings; it is therefore selected for parts liable to great and sudden strains, and exposed to constant wear and tear; tram plates, for example, heavy shafts, wheels, and ordinary steam cylinders, where large quantities of scrap are available. It is the opinion of many founders that a considerable advantage can be gained by a liberal use of No. 3, in conjunction with a smaller mixture of good soft pig iron.

No. 4 foundry iron, as it is called, when fractured, is more or less mottled, with a whitish glossy appearance. The pig is difficult to break, and the fracture uneven, indicating a considerable amount of tenacity. When melted very hot it has a clean, glowing surface, and as it is poured it throws out showers of sparks in all directions, which continue to break into small particles, and fuse during their flight. This phenomenon is peculiar to this description of iron, but may be observed with other irons which have been very much exposed and oxidized by the atmosphere. While still in a melted

state a constant succession of small globules rise to the surface, these expanding gradually and seeming to merge by degrees into the molten mass, being replaced continually while the iron remains fluid. On cooling, the surface is found covered by thin scales of oxide. No. 4 will be found applicable to very heavy castings, such as girders, bed plates, engine beams, plain columns, and the like, especially where there is little after machine manipulation necessary. It is obviously ill adapted for light casting, as its density renders it ill adapted for filling delicate moulds. The purely white irons are entirely unsuitable for foundry purposes, and are therefore beyond our consideration here.

The following remarks upon some points which we have already treated of may aid in roughly estimating the quality of a cast iron.

When the colour is a uniform dark grey, the iron is tough, provided there be also high metallic lustre; but if there be no metallic lustre the iron will be more easily crumbled than in the former case. The weakest sort ot cast iron is where the fracture is of a dark colour, mottled, and without lustre.

The iron may be accounted hard, tenacious, and stiff when the colour of the fracture is lightish grey, with a high metallic lustre.

When the colour is light grey, without metallic lustre, the iron is hard and brittle.

When the colour is dull white, the iron is still more hard and brittle than in the last case.

When the fracture is greyish white, interspersed with small radiating crystals, the iron is of the extreme degree of hardness and brittleness.

When cast iron is dissolved in muriate of lime, or muriate of magnesia, the specific gravity is reduced to 2·155; most of the iron is removed, and the remainder consists of graphite with the impurities of cast iron. A similar change takes place when weaver's paste is applied to iron cylinders. Sea-water, when applied for a considerable time, has the same effect. It takes much longer to saturate white cast iron than to affect grey. The soft grey iron yields easily to the file after the outer crust has been removed, and in a cold state is slightly malleable.

We may state also that the quality of iron in a melted state is readily judged of by a practised eye from the nature of the agitated

aspect of its surface. The mass of fluid seems to undergo a circulation within itself, having the appearance of ever varying network. When this network is minutely subdivided, it indicates soft iron. If, on the contrary, the iron be thrown up in large convolutions, the quality of the metal must be hard.

There are many individual exceptions to the ordinary classification of pig iron, which, although a matter of great convenience, is so far artificial, inasmuch as iron varies in quality, measured by the minuteness of the grain and foreign admixtures, by minute graduations between the two extremes. Considerable latitude is therefore allowed in the classification of pig iron.

"Scrap" or the broken-up fragments of every conceivable article which cast iron is employed to make, is as variable in composition as can well be imagined. A general characteristic is that it can be melted with less fuel, as it is deficient in the thick silicious skin which usually covers the pig, and more can be melted in a given time, as the silica necessitates a liberal use of limestone or some other flux, by which course damage frequently occurs to the lining of the cupola. It should be observed that "scrap" has become altered from its original composition as often as it has been remelted, for on every cooling the parts nearest the surface become white and hard, that is, to some extent chilled, and containing, therefore, more combined carbon than before, and hence its common daily use as an addition to soft pig, in order to confer upon the latter greater hardness and closer grain. It is a mistake, however, to suppose that a casting made with fine-grained scrap will have a finer grain than that of the pig employed to make it, for it is obvious from a slight consideration of the laws of crystallization, alluded to at page 23, that the fineness of the grain, that is, of the crystals in a finished casting, materially depends upon its size and the rate at which it cools.

It may not be out of place here to refer to the erroneous idea that repeated meltings improve the *quality* of cast iron; in fact, with many cases it is quite the reverse. Sir William Fairbairn gave this fallacy to the world some years since, and going forth as it did under the sanction of his name and justly regarded reputation, it has been repeatedly received as an established fact. To that great master of the founders' art, Robert Mallet, is due the disproval

of Fairbairn's conclusions, and the true view of the matter. Mallet says:—

"Every melting mixes it up with more or less finely divided oxides and silicates, in addition to which the earths, which are met with in the materials of the furnace, the fuel and the flux, often get reduced, and their bases in minute quantity alloyed with the iron. The conjoint effect of the foreign bodies and diffused oxides is to prevent the metal running clean in the moulds, or making sharp, sound castings; and the effect both of the diffused oxides and of the alloy with the metals of the earthy bases, is frequently to sensibly impair the ultimate cohesion of the cast iron.

"These evils are masked, or rather may be occasionally masked, by the increase of hardness, the approach towards white cast iron, which is produced by each successive cooling; but the combined effect is not that of improvement in the metal as a structural material, but a deterioration; for although it is, as is well known, a fact that the ultimate cohesion of white cast iron is much greater than that of grey or darker coloured metal, its coefficient of extensibility at rupture is a great deal less; in other words, the white cast iron is stronger, but not so tough.

"For these reasons, as well as others affecting the facility and perfection with which hard white cast iron is moulded, it is to mislead the practical iron founder to tell him that the oftener he melts and casts his good pig iron, up to '*thirteen* times' at least, the better it becomes. In brief, the facts are these:—1st. Every additional melting of cast iron injures, or is likely to injure, its quality as a structural material by the addition of foreign substances. These reduce the value of the coefficient of resistance at rupture, and may or may not reduce that of ultimate extension; that is, the metal, by remelting, becomes weaker, and may become more brittle. 2nd. Every additional cooling after melting increases the hardness, density, and coefficient of resistance at rupture of *the metal as last melted*, but constantly decreases the coefficient of ultimate extension, that is, the metal by re-cooling becomes stronger, but more brittle. The limit to these effects is found at the point where the whole of the cast iron has passed into the state of *white cast iron*, as it is produced in "the chill," or in the "finery ingot." The effects are more rapid as respects the *melting* in proportion as

foreign bodies, having more powerful affinities and in larger quantities, are presented to the cast iron in the furnace; we may add also, as the nature of these bodies shall be more or less injurious when combined therewith; and as respects the *cooling* are more rapid in proportion as the rate of cooling is more so. 3rd. The conjoint effect of repeated and alternate melting and cooling thus may or may not result in a material possessing a higher coefficient of ultimate cohesion at rupture, but will always result in one more brittle, and thus of less in place of greater structural value. As respects the properties of the material in the iron founder's view, its moulding properties are *always* deteriorated. 4th. If the cast iron *at the commencement* be assumed to be very bright grey mottled iron, or white iron, then it is certain that the effects of every subsequent melting, under the ordinary conditions of cupola or air furnace, must prove deteriorative, and that only."

The principal and most objectionable impurities found in iron and steel are sulphur, phosphorus, silicon, calcium, and magnesium. Sulphur and calcium make iron brittle at a red heat; this is called "red-short" iron; phosphorus and silicon make it brittle at low temperature; this is known as "cold-short" iron.

The latter is the greater defect of the two. To avoid sulphur, use fuel which is free from sulphur; iron, which has been smelted, or puddled with charcoal, or with coke, that is, free from sulphur, is the strongest and toughest. Hence the high estimation in which "charcoal" iron is held.

Phosphorus comes either from phosphate of lime contained in the ore, the fuel, or the flux, or from phosphate of iron in the ore, phosphorus being most abundant in those strata where animal remains are found.

The presence of calcium and silicon can only be avoided by the use of ores that contain neither silica nor lime, such as pure hæmatite, or pure magnetic iron ore.

Silicon makes iron brittle and hard, and has a similar effect on it as phosphorus; it is constantly found in cast iron; hot-blast iron has more silicon usually than is found in cold-blast iron.

Alloys of iron are but of small importance to the founder. The following may be briefly noted:—

Chromium does not readily combine with iron, which it causes to be excessively hard.

Arsenic imparts a fine white colour to iron, but makes it brittle.

Gold combines very readily with iron; it serves as a solder for small iron castings, such as breast-pins and similar articles.

Silver does not unite well with iron, but a little may be alloyed with it; it causes iron to be very hard and brittle. The alloy is very liable to corrosion.

Copper, if alloyed with iron, is not regarded as a homogeneous compound, but a small quantity of iron added to brass increases its tensile strength.

Tin, with iron, makes a hard, but beautiful alloy, and can be mixed in any given proportions, which, if nearly half-and-half, assumes a fine white colour, with the hardness and lustre of steel.

Alloys of iron are but seldom used at present, owing to the easy and economical ways in which it can be gilded, silvered, and galvanized, or coated with other metals.

Of the various brands of cast iron which are useful to the founder, Scotch pig iron is superior for most purposes to any other pig iron; a little Scotch No. 1 will give fluidity to inferior brands. Gartsherrie, Coltness, Langloan, Shotts No. 1, are in much demand on this account. This superiority may be partly attributable to the varieties of ironstone which occur in Scotland, and partly to the adaptability of Scotch coal under proper manipulation to produce No. 1 iron.

Coltness pig iron is almost exclusively used for foundry purposes, and is in very high demand owing to its high percentage of uncombined carbon, which makes it particularly suitable for mixing with the light grey qualities of charcoal iron produced on the Continent, and with old foundry scrap.

To good Scotch pig is frequently added a certain proportion, varying to suit the requirements of the case, of "all mine" Staffordshire iron.

Lilleshall pig iron is a celebrated cold-blast iron, remarkable for its strength and resistance to torsion and tensile strains in a manufactured state; hence it is generally kept in stock to be used as a mixture for the metal in any casting where strength is

of primary importance, and it is also very largely used in foundries for casting into soft or hard chilled rolls.

The following list gives the names of a few of the most celebrated British makers of good melting pig iron. These have been selected for no invidious reason, as there are many others making excellent foundry pig whose names are unknown to the writer:—

ROBERTS AND COMPANY	Tipton Green Furnaces. Make good melting iron for bedsteads, and forge iron.
H. B. WHITEHOUSE	Prior Fields, Bilston. Best melters.
BOWLING IRON COMPANY	Best melters.
J. H. PEARSON	Windmill End, Dudley.
COCHRANE AND CO.	Dudley.
MADELEY WOOD COMPANY ..	Shropshire.
W. BAIRD AND CO.	Gartsherrie, Scotland.
COLTNESS IRON COMPANY	Coltness, "
WILSON AND CO.	Summerlee, "
R. ADDIE	Langloan, "
W. DIXON	Govan, "
MERRY AND CO.	Carnbroe, "
SHOTTS IRON CO.	Shotts, "
BARROW HÆMATITE, IRON, AND STEEL CO.	Barrow. Iron for malleable castings.

In making ornamental casts, strength is of secondary consideration, but in machinery, and girders for structural purposes, it is of the first importance. In foundries where machinery is cast, or water pipes, or beams for bridges, or architecture, there should be means of testing the strength of their cast iron. The safest and best way of doing this is to have a standard pattern, say a bar 2 feet long, 1 inch thick, and 2 inches wide. This pattern is to be moulded in a particular flask, with uniformly dry sand, and cast inclined at a particular degree. The mixture of iron is made in a crucible melted in an air furnace. This proof-bar is fastened with one end in a vice, and at the other end a platform is suspended, upon which so much weight is piled as to break the bar. Its deflection or deviation from the straight line, or from its original position, is measured. In this way the relative strength as well as the degree of elasticity may be measured, and the relations of the strength of one mixture of iron

to another mixture are decided with great practical certainty. Under all conditions a mixture of several brands of iron is stronger than the average strength of the whole, each taken by itself. It is rare, therefore, to employ only one kind of iron in the foundry. Generally mixtures are made, varied according to the nature of the objects to be cast, the work to which they will be applied, and the strains to which they will be exposed. It is the power of making mixtures which possess these qualities, of various kinds of iron in the casting, that forms the principal advantage of the second fusion. The founder can thus modify entirely at will the nature of the metal according to the exigences of his work, and apply to each object the quality of iron best adapted for it.

A thorough acquaintance with the different kinds of cast iron and the results obtained by their mixture constitutes one of the qualifications of a good founder. It is like many other things very difficult to acquire, and can only be the fruit of numerous observations and a lengthened experience.

The kinds of pig iron which should be mixed, to obtain the best results, depend very much upon the situation of the foundry, and the qualities of iron which are most easily and cheaply procured in the immediate neighbourhood, and as the nominal brands of iron differ considerably in quality in various localities, only a few general considerations can be mentioned, as in purchasing the buyer will have to be guided mainly by his experience, and the possibilities of obtaining an article as near his requirements as his position affords.

If pig iron is too grey, or too spongy, it may be improved by adding No. 3 iron, or scraps from old castings, which are preferable.

Very black grey iron will bear an addition of 30 per cent. of No. 3 pig or scrap. Iron which contains too little carbon is successfully improved by adding No. 1 until the wished-for strength and texture are obtained. Iron from different furnaces ought to be mixed together, and if there is any possibility of obtaining iron from different localities and different ores, it is to be preferred.

In all cases, however, it is better to mix No. 1 of one kind with No. 2, 3, or 4, or scrap of another kind.

A mixture which makes a close and compact grey iron is the best both for strength and economy, but in each instance proper consideration must be given to the purposes for which the iron is required, as it by no means follows that a mixture which is excellent for one class of casting is even tolerably adapted for another class. Thus iron which makes a sharp clear casting for small ornamental work could not with safety be used for parts of heavy machinery, or for beams and girders.

Small or ornamental castings require a fusible iron, not too grey, which will soon solidify and take a clear sharp impression from the mould.

Iron which is a little cold short, containing a slight admixture of phosphorus, does well for such work; whilst for railings, or balustrades, or other purposes where the iron may be subjected to rather sudden strains, the pig should be fine grained, and free from phosphorus.

In order to obtain a metal having the utmost slipperiness of surface, manganiferous iron is strongly recommended. For heavy castings where great tensile strength is required, spiegeleisen should not be used; but if an iron is required that will be good for turning and boring, as in the case of steam-engine cylinders, a manganiferous iron must be used in such proportions as will render it most suitable for undergoing these operations. Spiegeleisen alone does not give the right metal, as it contains from 8 to 10 per cent. of manganese, which is too large a proportion; 2 or 3 per cent. of manganese is the best for giving a good slippery surface, which will continue in the best order in working, and is consequently well suited for horizontal, stationary, and locomotive cylinders, and for other sliding surfaces. A metal possessing great fluidity in melting can be obtained by a mixture of North Lincolnshire manganiferous iron with hæmatite and a little Scotch pig; this gives a close metal which, though difficult to file, can be turned and bored with facility. By the use of the simple ingredient manganese, added in proper proportions, iron for the exact character required for steam cylinders, slide valves, or motion bars, can be obtained.

While ordinary cast iron emits sparks when run from the furnace, and often gives off occasional bubbles of gas during its

cooling, iron containing manganese evolves so much combustible gas that upon the surface of the metal while flowing from the furnace is a sheet of burning gas. While the iron is cooling the gas is discharged in numerous jets. Iron containing manganese retains after solidification much more hydrogen than cast iron. A specimen of each kind of iron weighing 500 grammes (17·635 oz.) heated in a vacuum to 1472° Fahr., gave off the following quantities of gas:—

	Charcoal Iron.	Spiegeleisen.
Carbonic acid	0·6	0·0
Hydrogen	12·3	27·0
Carbonic oxide	2·8	0·0
Nitrogen	1·0	2·5

The carburetted manganese takes up much more hydrogen than iron carburetted to the same degree. It is seen, then, that the presence of manganese in cast iron increases materially the occlusion of hydrogen, and diminishes that of carbonic oxide.

A very good mixture for strong and close-grained cast iron for steam cylinders is composed of 8 parts, by weight, charcoal pig, No. 5; 10 parts, by weight, Scotch pig; 10 parts, by weight, scrap iron. Another is made of the following irons—Blaenavon (cold blast), Silverdale (Madeley Wood), Hæmatite, No. 7 or 8, and Glengarnock mixed with good scrap in varying proportions.

Where great hardness is required, an excellent mixture is 2 parts charcoal pig, No. 5; 4 parts Scotch pig; 30 parts scrap.

In order to get a perfectly homogeneous mixture, and at the same time to have the power of thoroughly examining the metal before finally casting, it is advisable to melt the metals together first, and cast in small ingots or pigs, which can be easily broken for testing and examination. If the mixture proves satisfactory, it can then be remelted, and cast in the mould. Such a precaution will often save the production of waster castings.

When a tough, close-grained casting is required, borings and turnings of wrought iron are often put in the cupola along with the broken pig. An instance of such a mixture is when a powerful hydraulic cylinder is to be cast, for unless the metal is very fine in the grain it will be useless for the purpose. Care and judgment exercised in the preparation of the charge of metal for the cupola

will always bring its own reward and substantially add to the reputation of any foundry.

Morris Stirling had a process for making tough iron, which consisted in putting pieces of wrought iron into cast iron, and passing them through the furnace together. Most practical iron founders have some particular mixtures of iron to which they attach great importance, and with reason, for upon the judicious union of different brands of iron the ultimate value of the casting for its special purpose mainly depends, and as carriage is an expensive item in dealing with so weighty a material, that which is lightest is, other things being equal, the best iron to employ.

CHAPTER II.

ON SOME POINTS TO BE OBSERVED IN DESIGNING CASTINGS, WITH ESPECIAL REFERENCE TO THE CRYSTALLINE FORMATION OF METALS.

IT seems scarcely possible to exaggerate the importance in designing castings, of so arranging their outlines as least to interfere with the natural laws of crystallization, which come into play during the cooling of the metal.

And yet this vital point of the founder's business has received but comparatively little attention from scientific authorities, and with the exception of a few able articles on the subject from Robert Mallet, F.R.S., and some excellent advice contained in Professor Kerl's 'Metallurgy,' there are few works in which it is possible to find much information.

The reason is not far to seek. Practical hard-working founders learn from bitter and costly experience to understand what designs are likely to result in faulty castings, and the exact points at which they will fail. But these persons are not writers of books as a rule. They content themselves generally with pointing out such a modification in the design as will remove its objectionable features, or send in a very high tender in order to cover all contingencies in the shape of *wasters*. An exception to this rule occurred a short time since, when Mr. J. M. Oubridge, of Middlesbrough, read a thoroughly practical paper on this subject, from which a few extracts are appended.

It is of vital importance that anyone who may have to design castings should thoroughly understand the problem, "How does the shape of the casting allow the lines of crystallization to flow so as to keep them in the most compact form, and so that the molecules are not separated by any unnatural force?"

The following remarks on crystallization will have no reference

either to iron or steel, when it has undergone the process of either rolling or hammering, for these so re-arrange the molecules as to direct them from their natural flow, just as when they pass from a liquid to a solid state. We must therefore confine our attention to metals passing from the liquid to the solid condition, by the act of crystallization; and more particularly to cast iron and brass, for it is to these that the founder has most frequently to direct his attention and to exercise his skill. Not unfrequently the founder gets the blame when some portion of a cast-iron structure has failed, even when no defects are apparent to the uninitiated. It is asserted that the founders have not put good metal in the casting, for that it has been calculated from a proper formula what quantity of material should carry the load required. At the same time it has not been considered in which way the lines of crystallization flow, nor by the addition of many excrescences to the casting, that they may have so distorted it as to render it comparatively a very weak thing.

Iron which has been poured into a mould, on changing from a liquid to a solid state, becomes a mass of crystals. These crystals are more or less irregular, but the form toward which they tend, and which they would assume if circumstances did not prevent, is that of a regular octahedron. This is an eight-sided figure, and may be imagined to be formed out of two pyramids, having their bases together.

In Fig. 1 is a group of crystals from pig iron, among which one has, by the aid of favourable circumstances, succeeded in gaining the natural form. In a perfect crystal of iron all the lines joining the opposite angles are of equal lengths and at right angles to each other. These lines are called the axes of the crystal.

Concerning this formation of crystals, Mallet observes, "It is a law of the molecular aggregation of crystalline solids that when their particles consolidate under the influence of heat in motion, their crystals arrange and group themselves with their principal axes in lines perpendicular to the cooling or heating surfaces of the solid, that is, in the direction of the heat-wave in motion, which is the direction of least pressure within the mass.

"This is true, whether in the case of heat passing from a previously fused solid in the act of cooling and crystallizing on conso-

lidation, or of a solid not having a crystalline structure, but capable of assuming one upon its temperature being sufficiently raised by heat applied to its external surface, and so passing into it.

"For example, if an ingot of sulphur, antimony, bismuth, zinc, hard white cast iron, or other crystallizable metal or atomic alloy, or even any binary or other compound salt, or hyaloid body, as sulphide of antimony, calomel, sal-ammoniac, various salts of baryta and lime, chloride of silver or lead, or even organic compounds, such as camphor and spermaceti, provided it only be capable of aggregating in a crystalline form under the influence of change of temperature, as from fusion or sublimation. If an ingot or mass of any such body be broken when cold, the principal axis of the crystals will always be found arranged in lines perpendicular to the bounding planes of the mass, that is to say, in the lines of direction in which the wave of heat has passed outwards from the mass in the act of consolidation."

Now, cast iron is one of those crystallizing bodies which, in consolidating, also obeys law more or less perfectly, according to the conditions, so that generally it may be enunciated as a fact, that in castings the planes of crystallization group themselves perpendicularly to the surface of the external contour; that is to say, in the direction in which the heat of the fluid cast iron has passed outward from the body in cooling and solidifying. This is because the crystals of cast iron are always small, and are never well pronounced. Their directions are seldom apparent to the eye, but they are not the less real. Their development depends :—

1. Upon the character of cast iron itself, whether or not it contains a large quantity of chemically uncombined carbon, suspended graphite, which Karsten has shown to be the case with all cast irons that present a coarse, large-grained, sub-crystalline, dark and graphitic, or shining spangled fracture. Such irons form in castings of equal size the largest crystals.

2. Upon the size or mass of the casting presenting for any given variety of cast iron the largest and coarsest aggregation of crystals, but by no means the most regular arrangement of them, which depends chiefly upon—

3. The rate at which the mass ot casting has been cooled, and

the regularity with which heat has been carried off by conduction from its surfaces to those of the mould adjacent to them; and hence it is that of all castings in iron, those called "chilled," that is to say, those in which the fluid iron is cast into a nearly cold and very thick mould of cast iron, whose high conducting power carries off the heat, present the most complete and perfect development of crystalline structure, perpendicular to the chilled surface of the casting.

In such the crystals are often found penetrating to an inch and a half or more into the substance of the metal clear and well-defined.

Those prevailing directions of crystalline arrangements may be made more clear by Figs. 3 and 5, Plate I., which are sections of a round and a square bar of any crystalline solids or of cast iron, when the crystallization is well developed, the circumstances affecting which we shall consider farther on. In the round bar the crystals are all radiating from the centre; in the square bar they are arranged perpendicularly to the four sides, and hence have four lines, in the diagonals of the square, in which terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

Fig. 4, Plate I., is a flat plate in section. The direction of the crystalline radiation here follows the planes of the figure, with the exception of one deviation. In it are the same diagonal lines of weakness. The pairs of diagonals, joining the corners nearest to each other, are joined by a long line parallel to the two long surfaces. This line is also a line of weakness, as the lines in which the crystals assemble in the systems belonging to each surface begin at the surface, and, as the casting cools, elongate toward the centre. When they meet in the middle they do not form continuous lines through from one surface to the other.

Castings may be made which will not show this peculiar appearance, and may not have it in any marked degree, but if such castings are exposed to heat the crystals will change position, and assemble in lines perpendicular to the surfaces through which the heat entered the casting. The greater the heat the more marked will be this peculiar structure, and the law, as before stated, applies

equally in this case, all the crystals finally assembling in lines perpendicular to the bounding surfaces which were heated.

This can be illustrated in the following manner:—Take two pieces of zinc which have been rolled into a sheet, and heat one of them just below the melting point. To illustrate the point in question, it must be remarked that rolling any metal into a sheet elongates each crystal in a direction perpendicular to the pressure exerted in rolling, that is, lengthwise in the sheet, and if the metal is drawn into wire, the crystals are lengthened in the same way. By bending the piece of zinc that has not been heated, it will be found that it is tough, and can be bent many times without breaking the crystals lengthwise. Take the other piece of zinc that has been exposed to heat. In it the crystals have turned round, and have formed themselves in lines perpendicular to the surface through which heat entered, and it will break when it is bent. The peculiar crystalline structure is varied somewhat by the quality of the metal used, but it depends more directly upon the amount of heat passing out, or, in casting, upon the rapidity with which the operation is performed.

It may here be remarked that in casting large thin plates, such as flooring plates, it is the practice of the founder, when they are cast open, to cover them over with loose sand as soon as the metal ceases to be liquid; and then to remove the sand, so as to expose the surface of the metal to the action of the air in a crosswise direction, as shown in Fig. 4; the object in doing so is the more rapidly to cool those portions where crystallization is longest in taking place. If this be not done, the plate not unfrequently "buckles," and thereby loses its uniform level surface, or sometimes it actually splits asunder. One of the difficulties founders have, is to keep large flat plates straight, or from flying into several pieces. Whenever, therefore, it is possible to cool them in the lines of the weakest points, and thereby to get the metal, by rapid cooling, as near as possible to the other parts, so much the better. This cannot be done at all times, for it is occasionally not possible to uncover those portions of a casting without cooling other portions, which would thus cool too rapidly, and so cause a greater evil. Thus it is that sometimes much judgment is needed so as to suit the

conformation of the casting, and to reduce the lines of crystallization into such forms as will in some measure avert destructive changes. In the large circular plate, to which is attached a large portion of a cylinder, as seen in Figs. 4 and 5, Plate II., it would be most difficult to get the centre portion to cool, and thereby crystallize in the same ratio as the outer edge, for the heat is so much concentrated in the centre that those portions of the mould cannot be removed until crystallization has almost come to rest. It is of great importance that the proportions of the metal should be arranged so as to neutralize those two divergencies, and also to reduce the lines to a minimum. If a circular plate, 9 ft. diameter, be cast and cut from the edge to the centre, as in Fig. 9, Plate I., the contraction of the iron by crystallization gives an opening of 1¼ in. The neutral strain upon this plate must be very great, and many such castings fly into pieces upon the least heat acting upon them. It is therefore necessary to rearrange its formation so as to reduce the crystallization to a minimum. This can be done by changing the form from a circle to one of the shape seen in Fig. 5, Plate II., taking off four sides, and thus reducing the strain. This example shows how important it is to pay strict attention in the following out of natural laws. If all those who have the designing for work would give more attention to such points as those indicated, it would be the means of saving master founders much money and time, and the former a great deal of anxiety and trouble.

In Fig. 7, Plate I., a section is shown of a hollow cylinder in which the arrangement of the crystals is always towards the centre or axis of the cylinder, whether the casting be that of a water pipe, a gun, or a mortar.

Fig. 11, Plate I., represents a portion of the lower end of the cylinder of the hydraulic press, as first made for raising the tubes of the Britannia Bridge, and which broke in the attempt, the end of the cylinder having given out from the sides, as in Fig. 10, Plate I., under the severe water pressure to which it was exposed; that is to say, the fracture took place all round and along the plane of junction of the coterminous crystals formed perpendicularly to the external and internal surfaces of the bottom and of the sides of the cylinder. This proves that such planes of junction are

planes of weakness—planes in which the cohesion of the metal is less than in any other parts of the mass.

The particular form of the bottom of the cylinder designed by Mr. Stephenson arose, no doubt, from a distinct appreciation of the fact that the fracture of the part was in some way connected with the sharp and sudden termination alluded to, though without apparently any clear conception having been entertained of the crystalline laws upon which the fact depended. A new cylinder was accordingly made, and a section of a portion of this is represented in Fig. 2, Plate II. This stood the strain put upon it, and remained uninjured.

Here the principal axes of the crystals are all directed to the centre. They therefore gradually change their direction, and thus no planes of weakness are produced. These considerations explain the general law as applied to cast-iron artillery, and which is as follows:—"That every abrupt change in the form of the exterior, every salient, and every re-entering angle, no matter how small, upon the exterior of a cylinder, gun, or mortar, is attended with an equally sudden change in the arrangement of the crystals of the metal, and that every such change is accompanied with one or more planes of weakness in the mass."

The natural remedy for this is to avoid all sharp angles, allowing the metal, when possible, to flow in curved lines instead of sharp square corners.

Figs. 1*a* and 1, Plate II., are sections of a cast-iron gun; the former part of the breech through the "ventfield" square to the axis of the bore, and a section near the trunnion also square to the axis of the bore. Fig. 3, Plate II., is the section of a reinforce ring. In the plane of the axis of all these there are shown, in an exaggerated form, the direction of crystalline aggregations and the planes of weakness resulting from it.

It will be remarked that the square projections of the "ventfield" produce at each angle planes of weakness which, in the case of re-entering angles, penetrate deep into the body of the gun. That these planes really do exist is evidenced by the lines of fracture in bursted guns, which almost always follow along the angles of the sides of the "ventfield." The same may be said of

hydraulic cylinders when a boss is cast on whereto to affix the connecting pipe and the pumps, and also in the trunnions of guns. A gun, like every other metallic substance that fails under strain, must fail in the weakest place, and the places of fracture and position of these planes of weakness coincide most remarkably. The conclusion, therefore, seems inevitable, that, however incapable the unaided eye may be to discover any differences in the crystalline arrangements of the various parts of castings, such planes of weakness do exist in the positions and from the causes pointed out.

To obviate two unfavourable conditions, it is best to cast a cylinder or tube hollow, to suspend the core of the mould from the top or head, insert a perforated tube down the interior of the core, and then inject a current of cold air into the interior of the casting. In America some use water to cool such interiors; cold air is, however, as most easy of application, less dangerous, and more effective. The fact is, that by injecting cold air down the core the central heat is reduced and placed on an equality with that of the external surface, thereby getting rapid crystallization. The densities of the outer and inner surfaces are also thus made uniform with each other.

Now as regularity of development of the crystals in cast iron depends upon the regularity with which the melted mass cools, and the wave of heat is transmitted from the interior to its surface, arranging the crystals in the lines of least pressure in its transit, so the extent of development, or, what is the same thing, the size of each crystal, depends upon the length of time during which the process of crystalline arrangement goes on, that is to say, upon the length of time the casting takes to cool.

The lower the temperature at which the fluid cast iron is poured into the mould, and the more rapidly the mass is cooled down to solidification, the closer will be the grain of the metal, the smaller the crystals, the fewer and less injurious the planes of weakness, and the greater the specific gravity of the casting. The very lowest temperature at which metal can be poured, so as to fill every cavity of the mould without risk of defect, is that at which a large casting, such as a heavy gun, a hydraulic cylinder, or a

large anvil block, ought to be produced. It is here, however, that the difficulty of the founder begins, and especially where castings of a complicated form are required. The point, then, is to get every portion of the mould filled without cold shots, or collections of impurities arising in the metal from eddies or other obstructions. It is thus an absolute necessity to have the metal as liquid as possible, and to get the mould filled as rapidly as it can be done. Founders know well that accumulations of a deteriorating kind occur with dull metal and slow running; and experience has taught that castings are much more free from defects, both of cold shots and impurities, by using hot metal, although the crystallization is not so perfect in heavy castings.

Irons are often melted together, having different degrees of fusibility; they will perhaps mix, but not combine properly with each other.

These irons, having different melting points, will shrink unequally, and not having become united into one homogeneous body, but existing separately, each one will pull the other, and, if possible, pull completely away, causing the casting to break. No. 1 iron has a higher melting point than No. 2, made from the same ores, and not only do different grades of iron shrink differently, but of castings poured from the same metal a small casting will shrink more than a heavy one. Excess of heat in every case, however, increases shrinkage. The lower the melting point the less shrinkage. Experiments show, as in the case of other alloys, that a mixture of two brands of iron may have a lower melting point than either of them when used separately, and on the other hand, a mixture of a number of brands of iron may have a higher melting point than any one of the brands used singly. It is generally considered that charcoal iron has a higher melting point than coke iron. Following up the statement that of castings poured from the same iron, the light shrinks more than the heavy casting, it follows that in making a pattern no part should be thicker than another. Of course it is not possible in practice to adhere to this axiom. Much, however, may be done to avoid very sudden contractions in shape. Fig. 2, Plate I., is an instance of one of the worst forms for a casting, with a thick part and a thin part immediately adjoining.

The thin part naturally cools first, shrinking down to its final dimensions, leaving the thick portion still partially molten. When the thick portion cools the particles next to the thin part at A B tend to contract away from the part already cool. This may cause the thin part to buckle out of shape, but the internal strain in any case will be such that a very slight blow will break the casting in two.

CHAPTER III.

FURNACES AND FUEL.

Furnaces are used in metallurgical operations either for producing permanent changes in the materials heated, or for preparing them by softening and fusion for subsequent treatment. The design, materials of construction, and mode of working of furnaces are of a very varied description, but they may be broadly divided into two distinct branches, one in which the solid fuel is intermixed with or directly surrounds the materials to be heated, the other that in which the heating is done by flame, without direct contact between the metal or ore and the solid fuel.

This classification also applies to the fuel used, which is essentially different in each of these two branches. In the first branch, say, for a cupola or coke furnace, for melting steel or brass in crucibles, an intense local heat is required in the mass of the fuel itself, and the heat developed on its surface is practically useless. For this class of work the most suitable fuel is charcoal, coke, or anthracite, consisting of nearly pure carbon with little volatile matter.

In the other branch, flame furnaces, such as are used for glass melting, puddling or heating iron, the materials to be heated are placed in a chamber at the side, or above, the fuel, the heat of the flames being made use of by being carried into the working chamber by currents of gases rising from the fire, together with that due to their combustion on admixture with additional air. For furnaces of this description a full supply of combustible and partly burned gases at a high temperature is required, which gases are to complete their combustion in the working chamber, so as to heat the materials placed therein to the highest possible degree.

The fuel preferred for this purpose is gas, or coal, or dried wood. Flame may also be obtained from fuel containing little

else than carbon and mineral matter by placing it in a thick bed, and by introducing with the air required for combustion a large proportion of steam. The gases produced by the decomposition of the steam, and by the passage of the air through the fuel, flow forward into the mixing chamber where they ignite.

In the small furnaces fired with coke, such as are commonly used for melting steel or brass in crucibles, the latter are imbedded in the fuel, and a rapid combustion with a high temperature is maintained round them by closing the upper part of the furnace and connecting it with a tall chimney.

Where, as in smiths' fires, the top of the chimney cannot conveniently be closed in, or where a keener combustion is required than can be obtained by chimney draught, air is forced into the furnace by mechanical means.

Blast furnaces and cupolas so arranged are largely used in smelting the ores of iron, copper, and lead, and in fusing cast iron. The fuel and materials to be acted upon are charged together into the upper part of a vertical furnace, and the combustion is supported by air forced in through openings called *tuyeres*, near the bottom. Such furnaces and cupolas for the production of cast iron are built of great size, and require much skill in designing and construction to obtain good results, with an economical expenditure of fuel.

In the flame furnaces the useful effect of the heat is obtained by bringing a flame to bear upon the material to be heated, instead of imbedding it in solid fuel. Such a furnace is the reverberatory, which consists of a fire-grate, and a flame chamber, which leads the products of combustion away to the chimney, the flame in its passage *reverberating*, or being deflected upon the material to be heated. In the same branch of furnaces, though widely different in construction, comes the Siemens' regenerative gas furnace, now so largely used for a variety of purposes where a high temperature is required.

There are, therefore, three distinct classes of furnaces, the cupola, the reverberatory, and the crucible or pot furnaces, in each of which there are many variations of design to suit the different purposes for which they are intended. In the cupola no metal but iron is melted.

Copper, bronze, brass, German silver, silver, gold, and the alloys of these metals, are either melted in crucibles, or, if dealt with in larger quantities, in the reverberatory furnace. The furnaces and tools are essentially the same for other metals as those described for the smelting of iron, with a few slight modifications in detail in the cases of the more fusible metals, such as lead, tin, &c., which may be melted in iron pots, kettles, or clay crucibles.

"Fuel in the ordinary acceptation of the term, is carbonaceous matter, which may be in the solid, the liquid, or in the gaseous condition, and which, in combining with oxygen, gives rise to the phenomenon of heat." Such is the definition of Dr. Siemens in a valuable paper on *Fuel*, and the learned Doctor goes on to give the following description of its action and power.

Commonly speaking, this development of heat is accompanied by flame, because the substance produced in combustion is gaseous. In burning coal, for instance, on a fire-grate, the oxygen of the atmosphere enters into combination with the solid carbon of the coal and produces carbonic acid, a gas which enters the atmosphere of which it forms a necessary constituent, since, without it, the growth of trees and other plants would be impossible. But combustion is not necessarily accompanied by flame, or even by a display of intense heat. The metal magnesium burns with a great display of light and heat, but without flame, because the product of combustion is not a gas but a solid, viz. oxide of magnesium. Again, metallic iron, if in a finely divided state, ignites when exposed to the atmosphere, giving rise to the phenomena of heat and light without flame, because the result of combustion is iron oxide or rust; but the same iron, if presented to the atmosphere in a solid condition, does not ignite, but is nevertheless gradually converted into metallic oxide or rust as before.

Here is then combustion without the phenomena either of flame or light; but by careful experiment it is found that heat is nevertheless produced, and that the amount of heat so produced precisely equals that obtained more rapidly in exposing pulverulent iron to the action of oxygen. Only in the latter case the heat is developed by slow degrees, and is dispersed as soon as produced,

whereas in the former the rate of production exceeds the rate of dispersion, and heat therefore accumulates to the extent of raising the mass to redness. It is evident from these experiments that we have to widen our conception, and call fuel "any substance which is capable of entering into combination with another substance, and in so doing gives rise to the phenomena of heat."

In thus defining fuel, it might appear at first sight that we should find upon our earth a great variety, and an inexhaustible supply of substances that might be ranged under this head; but a closer investigation reveals the fact, that its supply is, comparatively speaking, extremely limited. The sun whose beams are the physical cause of everything that moves and lives, or that has the power within itself of imparting life or motion on our earth, is made perceptible to our senses in the form of heat; but it is fair to ask, what is heat, that it should be capable of coming to us from the sun, and being treasured up in our fuel deposits both below and on the surface of the earth?

Heat, according to the "dynamical theory," is motion amongst the particles of the substance heated, which motion, when once produced, may be changed in its direction and its nature, and thus be converted into mechanical effect, expressible in foot pounds, or horse-power. By intensifying this motion among the particles, it is made evident to our visual organs by the emanation of light, which is vibratory motion imparted by the ignited subtance to the medium separating us from the same. According to this theory, which constitutes one of the most important advances in science of the present century, heat, light, electricity, and chemical action are only different manifestations of "energy of matter," mutually convertible, but as indestructible as matter itself. Energy exists in two forms, "dynamic" or "kinetic energy," or force manifesting itself to our senses as weight in motion, as sensible heat, or as an active electrical current; and "potential energy," or force in a dormant condition. In illustration of these two forms of energy take the case of lifting a weight, say 1 lb. 1 foot high. In lifting this weight, kinetic, muscular energy has to be exercised in overcoming the force of gravitation of the earth. The pound weight, when supported at the higher level to which it has been raised, represents "potential energy" to the amount of one unit or

"foot pound." This potential energy may be utilized, in imparting motion to mechanism, during its descent, whereby a unit amount of "work" is accomplished. A pound of carbon, then, when raised through the space of 1 foot from the earth, represents, mechanically speaking, a unit quantity of energy, but the same pound of carbon wnen separated, or, so to speak, lifted away from oxygen, to which it has a very powerful attraction, is capable of developing no less than 11,000,000 foot pounds or unit quantities of energy, whenever the barrier to their combination, namely, excessive depression of temperature, is removed; in other words, the mechanical energy set free in the combustion of 1 lb. of pure carbon is the same as would be required to raise 11,000,000 lbs. weight 1 foot high, or as would sustain the work which we call a horse-power during 5 hours 33 minutes. In burning 1 lb. of carbon in the presence of free oxygen, carbonic acid is produced and 14,500 units of heat (a unit of heat is 1 lb. of water raised through 1° Fahr.) are liberated. Each unit of heat is convertible (as proved by the deductions of Mayer, and the actual measurements of Joule) into 774 units of force or mechanical energy; hence 1 lb. ot carbon represents really $14,500 \times 774 = 11,223,000$ units ot potential energy. We thus arrive at the utmost limits of work which we can ever hope to accomplish by the combustion of 1 lb. of carbonaceous matter.

The three great branches of the consumption of fuel are:—

The Production of Steam Power,

The Domestic Hearth, and

Metallurgical and Chemical Furnaces.

In each branch considerable waste of fuel takes place, that is to say, that owing to defective or unskilful arrangements for the utilization of the heat obtained by the combustion of fuel, nothing at all approaching its theoretical power is produced.

Having alluded to several improvements by which savings might be effected in the two first branches above mentioned, which we need not here recapitulate, Dr. Siemens proceeded to consider the Consumption of Fuel in Smelting Operations. The smelting or metallurgical furnace consumes about 40,000,000 of the 120,000,000 tons of the coal produced. Here is great room for improvement.

The actual quantity of fuel consumed in heating a ton of iron up to the welding point, or in melting a ton of steel, is more in excess of the theoretical quantity required for these purposes than is the case with regard to the production of steam power and to domestic consumption. Taking the specific heat of iron at ·114, and the welding heat at 29,000° Fahr., it would require $·114 \times 2900 = 331$ heat units to heat 1 lb. of iron. A pound of pure carbon develops 14,500 heat units, a pound of common coal, say 12,000, and therefore one ton of coal should bring 36 tons of iron up to the welding point.

In an ordinary reheating furnace, a ton of coal heats only $1\frac{2}{3}$ ton of iron, and therefore produces only $\frac{1}{21}$ part of the maximum theoretical effect. In melting, 1 ton of steel in pots, $2\frac{1}{2}$ tons of coke are consumed; and, taking the melting point of steel at 3600° Fahr., the specific heat at ·119, it takes $·119 \times 3600 = 428$ heat units to melt a pound of steel; and, taking the heat-producing power of common coke also at 12,000 units, 1 ton of coke ought to be able to melt 28 tons of steel. The Sheffield pot steel-melting furnace therefore only utilizes $\frac{1}{70}$ part of the theoretical heat developed in the combustion.

Having thus briefly considered the theoretical bearings of the subject of fuel, let us now see what are the practical conditions of the fuels adapted for our purposes.

Table II. gives several analyses of good coals for metallurgical purposes; No. 1 is of a coal which is coked in the neighbourhood

TABLE II.—ANALYSES OF COAL.

	1	2	3	4	5	6
Carbon	80·4	84·57	78·0	77·5	92·62	91·5
Hydrogen	5·7	4·75	7·8	5·0	3·95	3·5
Nitrogen	1·2	1·15	1·6	1·5	{with oxygen}	0·3
Sulphur	0·9	0·60	1·6	0·5	trace	0·6
Oxygen	5·3	5·22	2·8	9·1	2·72	2·6
Ash-water	6·5	3·71	8·2	6·4	0·73	1·5

of Pontypool; 2 is of a Newcastle coal from Redheugh Colliery; 3 is also from the Newcastle District; 4 is Scotch, and has been

employed at Gartsherrie; 5 and 6 are anthracites from South Wales.

The applicability of any coal to a particular metallurgical purpose must depend upon a careful examination of its action when burning, physical characters, and some such analysis as those that are given in the above examples.

A primary condition which any kind of coal must fulfil to render it fit for employment in iron manufacture, whatever its qualities may be in other respects, is that it shall be free from sulphur. The presence of sulphur in iron is very deleterious to its quality, producing that state of its constituted particles which is technically known as "red shortness." Hence the fuel employed in its manufacture must not be capable of communicating this substance to it. It is mainly for this reason that wood charcoal is employed when iron of an unusually tough character is required. All coals contain sulphur; the purest from ½ to 1 per cent.; the most impure, 3 and even more per cent. When the proportion exceeds 1½ per cent., the coal becomes unfit in its raw state for metallurgical purposes. Thus the visible presence of iron pyrites will at once show the unsuitable character of the coal.

When a given specimen of the coal has been proved to fulfil this primary condition of freedom from sulphur, it remains to test its other qualities which may render it a good metallurgical coal. The calorific power of a coal is, as we have shown, proportional to the amount of carbon it contains. The proportion of ash represents so much loss of heat, besides the inconvenience which the presence of such matter occasions. A greater loss is due to the quantity of water present, for not only does the water constitute a negative loss proportionate to its amount, but a positive loss equal in amount to the quantity of heat abstracted to evaporate the water. Thus, a large proportion of either ash or of moisture, or of both, tends to render a coal unsuitable. In metallurgical operations, intense local heat is required, and hence the coal employed must contain a very large proportion of carbon. This condition excludes the flaming and the fuliginous varieties of the bituminous, and those of the gaseous classes altogether in their raw state. The anthracitous and the semi-bituminous classes, therefore, with the clear-burning varieties of the bituminous class, can alone be considered applicable

to this use. The two former classes also possess two other qualities which are required in the cupola, but which are not found in bituminous coal, namely, strength and freedom from a liability to cake. The great weight of the charge would crush a tender coal to powder, and an agglomeration of the mass would seriously impede the draught. The variety which best fulfils all these conditions is anthracite, but it possesses defects which go far to render it unsuitable. Though very strong naturally, it may be reduced by decrepitation in the furnace to the state to which the weakest is brought by pressure. It, moreover, requires, on account of its difficult combustion, a high-pressure hot blast, and a special construction of the furnace, to avoid a slow descent of the charges, and a consequent loss in the quantity of the metal produced. In consequence of these defects, anthracite is not largely employed where more suitable varieties are easily procurable. Such varieties are those of the anthracitous and many of the semi-bituminous classes.

The defects possessed by coals of the bituminous class may be removed by coking. This process expels the volatile matters, and leaves as a residue the carbon and the ash. In this state, that is when converted into coke, provided the conditions of freedom from sulphur and a large proportion of ash be fulfilled, clear burning coals of the bituminous class are more suitable for metallurgical purposes than those of the anthracitous and semi-bituminous classes, and they are very largely employed. In coke, carbon attains its maximum proportions, and the hardness and the strength of the combustible their maximum degree. Another advantage of converting bituminous coal into coke is, that it allows the small coal, which, as such, is nearly worthless, to be utilized. Coals of this class do not all coke with equal readiness, nor is the coke obtained from them of equal quality. Some varieties require a quick heat to produce the best results, while some others will not coke at all after some days' exposure to the atmosphere. These peculiarities demand careful attention. One important gain from the process of coking consists in the removal of the sulphur present, thereby enabling a coal to be utilized for metallurgical purposes that would be otherwise unfit for that use. Coke, to be suitable for the furnace, besides freedom from sulphur and ash, must possess the qualities of hardness, compactness, and strength to withstand con-

siderable crushing force; that which is brittle or liable to crumble and form dust is useless for the purpose. It is also of little value unless it can be obtained in large prismatic pieces. Hence, good coke, on cooling, should split into such pieces, somewhat in the manner of columnar basalt. Its colour should be steel grey, almost approaching to a silvery whiteness. An iridescent hue indicates the presence of sulphur. When struck it should emit a clear and almost metallic ring. Frequently a large proportion of moisture is imparted to coke by the thoughtless way in which the extinction is conducted by the burners. By the application of large quantities of water, evils are entailed of the first magnitude in the economical working of the furnace. Coke is the common fuel for the cupola in countries where semi-bituminous coal is abundant, while in others, such as the United States, in which anthracite is the prevailing coal, this is largely employed.

Other things being equal, a compact hard coal is the best for the cupola; and it should also be free from the defect of slacking down when heated. It should be borne in mind that if inferior soft coal has to be used, a larger quantity is required. It is a fallacy to suppose that large coal is conducive to good founding; small coal, that is, within reasonable limits, if clean and of good quality, is by far preferable for many reasons; one being that the iron with small coal melts from the bottom of the bed, as it should do, and so ensures good metal and regular working.

Charcoal, being expensive on first cost, is but seldom used, and that only in isolated districts where wood is of extreme abundance and easy carriage.

CHAPTER IV.

THE CUPOLA; ITS USES, ARRANGEMENT, AND CONSTRUCTION.

The cupola has the great advantages of melting iron cheaper than any other furnace, and of being a very convenient apparatus, as from half a hundredweight to five or six tons may be melted in a short time, with a comparatively small quantity of fuel, in furnaces differing only slightly in size and form. Consequently, in all cases where the strength of the metal is not of primary importance, the cupola is the most useful furnace.

The cupola, being only intermittently at work, does not afford the same facilities for utilizing the waste heat passing off from the top as does the blast furnace. The same reason also militates against economy of fuel, as the cupola has to be "lit up" very frequently, an operation which consumes a large proportion of the fuel used. Yet a well-constructed and properly managed cupola is a tolerably efficient apparatus, and does not offer a margin for any very material decrease in the consumption of fuel, which, with fair materials and management, may be taken to average 2½ cwt. of good coke to the ton of liquid iron, although the work has been done with a much smaller consumption of fuel. The quantity of coke that would be required theoretically to melt a ton of cast iron is only about 59 lbs.; but, in addition to this duty, it must be remembered that a large quantity of air has to be consumed in the shape of blast, and also that a certain proportion of the fuel must pass off unconsumed, in the form of waste gas from the top. It has been proposed to utilize this gas by drawing it along flues from the top of the cupola, in which flues the coke and pig iron were to be previously stacked, so as to be thoroughly dried, and somewhat heated before being charged into the cupola. Opinions differ as to the amount of economy that could be effected by such an arrange-

ment, but one thing is perfectly clear, namely, that if *damp* coke is charged into a cupola, a certain amount of heat must be wasted to evaporate that moisture before any duty can be obtained from the coke. Taking the theoretical quantity of coke that should melt a ton of cast iron at 59 lbs., and allowing 10 per cent. for moisture, 10 per cent. for loss by radiation, and 20 per cent. for waste heat passing away to the chimney, or 40 per cent. addition to 59 lbs., we find that in practice about 83 lbs. of coke should be capable of melting a ton of cast iron, whereas it frequently takes three times that amount.

Before describing the construction of the cupolas now in use, a short account of the old-fashioned rectangular cupola will be of service, as giving an opportunity of pointing out those defects in construction which led to its being discarded, and which defects, of course, should be avoided in all modern foundries.

The old cupola was an oblong square on plan, its longer sides being in the ratio of about 2 to 1½ of the shorter sides, and the height varying from 3 to 4 times the length of the longer side. Its shape was not one at all likely to give strength, and appears to have been adopted for no other reason than that the fire-bricks for the lining were then not generally procurable in any other than the common square form. The external casing was formed of cast-iron plates, with flanges at the angles; the sides were parallel and vertical, and the lining of fire-brick was set in fire-clay. The cupola was built on a platform of common brickwork, facing the sand floor, and the blast-pipes were brought up at the back. There were five or six tuyere holes one above the other, 9 or 10 inches apart, on each side of the cupola, and two sets of tuyeres were employed; these consisted of elbow pipes of copper, connected by a flexible leather hose to the cast-iron blast-pipes coming from the fan. The flexible hose were required, to allow of the tuyeres being gradually shifted up during the smelting operation, but they gave rise to considerable trouble, as if any serious leakage of air through one of them occurred, that particular tuyere would be temporarily disabled, whilst the tuyere on the other side would force out a fierce flame from the tuyere hole. Having all the tuyere holes but the two lowest stopped up with sand, and the tap hole open, the furnace was charged with coke and ignited, the "breast" of the

tap-hole was then closed, leaving the tap-hole itself open, and blast turned on at the two lowest tuyere holes. Scrap and pig iron, a proportionate supply of limestone, and coke were then supplied from a platform by the furnace man, until the iron began to run from the tap-hole, which was then also closed. When the furnace man saw, through the tuyere holes, that the melted iron nearly reached the level of the tuyere holes then in use, he raised the tuyeres to the holes next above, carefully stopping the lower ones. This process was repeated until either the cupola was as full as it could safely be, or until what was considered a sufficient quantity of metal was ready to tap for the work in hand.

The breast, which was about 12 inches wide, by 15 inches high, was simply stopped by sand, which was occasionally forced out by the pressure of metal within.

Owing to the long time occupied in melting all the iron contained in these cupolas, the sand stopping of the tap-hole frequently got burnt into a hard, slaggy substance, through which the tapping bar could only be driven by great force, and this frequently brought away the whole sand breast, followed by a rush of molten metal.

In modern practice the cupola is built of a cylindrical form, the casing being either of wrought-iron plates or of cast iron. When the casing is of cast iron it is advisable to strengthen it with wrought-iron hoops, especially in the case of a large cupola. Cast-iron casing is most durable, and can be made to a neat design, with projecting flanges to bolt the segments together, and upon which the wrought-iron hoops should be shrunk whilst hot. The economy of coke is principally determined by having the cupola of the correct height proportionate to its diameter.

When the maximum diameter does not exceed 4 feet, the height may range from five to six times the diameter. With cupolas having a larger diameter than 4 feet, the height should not exceed four to five diameters, up to the feeding aperture.

The objection to a very great height of cupola is the increased time and labour involved in raising the materials for charging, and wherever the height is considerable efficient mechanical arrangements are, of course, required for this purpose.

The diameter of cupola is also subject to much variation,

ranging from 18 inches up to 4 feet, or even larger. A cupola 18 inches wide, with one tuyere, will make good hot metal if worked with *charcoal*, but to work satisfactorily with coke requires a cupola at least 2 feet diameter with two tuyeres; and with anthracite a cupola, to produce the same result, should be 2 feet 6 inches diameter. A well-built chimney should be connected to the cupola, although for moderate-sized works a sheet-iron chimney is generally found to answer.

The prevailing interior horizontal section of the majority of cupolas is, at the present time, circular, however varied in other respects they may be. Figs. 2 and 3, Plate III., show back and front elevations of a common English circular cupola, having its interior sides perfectly perpendicular. A is a conical sheet-iron hood, communicating with the chimney, with an opening B for charging the cupola. C is the casing of thick wrought-iron plates, strongly riveted together. D are tuyere holes, about 6 inches diameter, the lowest being placed at 30 inches from the bottom of the cupola, the others about 15 inches apart in a vertical line. E is the tap-hole, towards which the bottom of the cupola must have a gentle slope; F, the iron base-plate; G, foundation. A cupola of this construction, 9 feet high and 3 feet 6 inches diameter inside the lining, is capable of melting a charge of 5 tons of cast iron.

The following are the leading dimensions of a well-constructed ordinary cupola, similar in form to that described:—

	ft.	in.
Outside diameter	4	6
Height above hearth	15	0
Inside diameter at tuyeres	3	0
Inside diameter at hearth	3	6
Inside diameter at top (plated with $\frac{5}{16}$-inch plate 14 feet above hearth)	3	0
Main blast-pipe .. .. (diameter)	0	15
Branch pipes (two)	0	8¾
Tuyere nozzles	0	7
Height of hearth above foundry floor .. (about)	3	0

A cupola of this description has been known to melt from 10 to 20 tons of iron a day with but 120 lbs. of coke to the ton of

metal melted, which consisted of various mixtures of Cleveland hæmatite and Scotch pig. The diameter was 3 feet 6 inches; height from tapping hole to charging floor, 14 feet. It was supplied with blast from a blower, at a pressure of ·25 lb. to the square inch, and melted at the rate of about 5½ tons an hour.

Fig. 1, Plate IV., is a front elevation of an ordinary cupola of large size, employed some years ago in a Glasgow foundry; Fig. 2 is a vertical section on a plane at right angles to that of Fig. 1; Fig. 3 is a horizontal section at the tuyeres; *a* is the charging door, about 2 feet square, by which the pig iron and coke are introduced into the furnace; *b* is the tapping hole, 15 inches square, at which the melted metal is occasionally drawn from the furnace; *c e*, not seen in Fig. 3, are the tuyere holes or apertures by which the blast enters, to afford a supply of air capable of maintaining a sufficiently intense heat in the furnace by combination with the fuel. These apertures are of considerable extent upwards, so as to admit of the tuyeres being set at any height required, which is regulated by the quantity of metal that may be collected in the furnace; for, of course, the tuyeres must always deliver the air clear of the surface of the metal. The under part of the structure below the charging door is the most essential division, and is indeed that which gives its character to the furnace. The upper portion is the chimney intended to convey away the volatile noxious products of the whole operation of fusion, being sufficiently long to pass out of the roof of the foundry. The furnace is built entirely of fire-brick, and it will be observed that the trunk is encased in cast-iron plates bolted together. The casing is in some instances cast in one or two entire cylindrical pieces, and in other instances it is made of boiler plates riveted together. The latter is undoubtedly the more durable material, as it stands the alternate expansion and contraction with much less injury to itself. The chimney is simply bound with wrought-iron belts, fastened round it at regular intervals. The whole structure stands upon a square base plate, of which the centre is cut out into a circular aperture; this plate is bedded upon brick or stone foundation represented in the figures. As the bottom must be protected from the action of the melted metal, which collects there, it is laid over with a bed of

sand, mixed with wet loam to give it consistency. This is shown in section at *d*, Fig. 2. It is continued over the bottom and sides of the spout *b*.

The following are the principal dimensions of this cupola:—

	ft.	in.
Diameter at hearth	4	10
„ charging floor	3	0
„ top of chimney	1	6
Height from base-plate to the sill of charging door	8	4
„ from door-sill to top of chimney	18	0

The cupola, Fig. 4, Plate IV., in general construction is similar to the preceding, but differs in its interior form, which is as nearly as can be cylindrical, as it tapers inwards but 3 inches from the base-plate to the charging door, a distance of 7 feet. The dimensions are:—

	ft.	in.
Diameter at hearth	3	3
„ charging door	3	0
„ top of chimney	2	6
Height from base-plate to sill of charging door ..	7	0
„ from door-sill to top of chimney	16	0

Fig. 1, Plate III., is of a furnace, said to have worked with very favourable results; it was termed an expanding cupola, and its peculiar form was designed for the purpose of retaining as much of the fugitive heat as possible to the charge. This cupola, 3 feet wide at the tuyeres, is of double this width at the charging door, where it is 6 feet wide. The expansion of the form of the furnace springs at a level little above the ordinary level of the tuyeres, so that it may be the more gradually accomplished, which prevents the occurrence of hinging or blocking up; and, indeed, the form of the cupola was so calculated that the metal should be melted before reaching the parallel part at the tuyeres. The great expanse at the charging door certainly admits of the use of heavy charges with great advantage, and it seems well adapted for running down large quantities of very hot metal for hollow cones and the like. The following Table affords a comparison of the three cupolas last particularized, all working with the same coke, and running metal for the purpose just mentioned:—

TABLE III.—CUPOLAS.

	Fig. 2, Plate IV.	Fig. 4, Plate IV.	Fig. 1, Plate III.
Initial charge of coke .. cwts.	12	8½	8½
First charge of iron	12	6	10
Second charge of coke	1¾	1½	1½
Second charge of iron	20	15	20
Running consumption of coke per ton	1¾	2	1½
Coke required to melt 5 tons ..	20	18	15½
Rate of melting per hour tons	5	3	6
Pressure of blast in ounces ..	4	4	4
Diameter of tuyeres in inches	5½	5½	5½

The construction of Krigar's cupola is shown in Figs. 1 to 4, Plate IX. Fig. 2 is a vertical section from front to back; Fig. 1, a vertical section from side to side; and Figs. 3 and 4 are sectional plans at different levels.

The vertical shaft A A of the cupola is made rectangular in form, either square or oblong, as shown in the plan, Fig. 3, and parallel, or very little taper in height, so as to avoid any prominent part upon which the flame could strike, and which would be exposed to rapid destruction. A backing of sand is used behind the brickwork to concentrate the heat in the cupola. The shaft A is supported at front and back by arches B B, over the lower chamber C C; and at the sides of this chamber is also a backing of sand, as shown in Fig. 4, to keep the heat in. Over this backing and round the bottom of the shaft A runs the air passage D D into which the blast is delivered from the two mains E E, and the blast entering through this passage cools the brickwork in the cupola, and becomes heated itself; it then passes down into the melting chamber C C, through the two long slots F F in the roof, one at the front and the other at the back, extending the whole breadth of the hearth as shown in the plans, Figs. 3 and 4. These slots are constructed by leaving a space of 4½ inches width between the outer arches G G, Fig. 2, and the inner arches B B that carry the shaft A; the length of the arch H, from front to back, is consequently made greater than the breadth. The front of the cupola is closed by an iron door K on hinges, extending the whole breadth of the hearth; and a smaller door L is placed at the back, to facilitate the drawing of the cupola, by inserting a rake at the back;

by this means the drawing of the cupola can be accomplished regularly within three or four minutes.

For starting the cupola, about 1 to 1½ cwt. of coke is placed on shavings or some burning coke upon the hearth, and more is added by degrees from the front door, until all the coke intended for the first filling is put in. The door K is then closed, being first wetted on the inside; and the tapping hole J is formed, as usual, by placing clay round a wetted stick. The whole height of the door is next plastered on the inside with a mixture of clay and sand; the door is then set forwards about 5 inches in front of the breast of the furnace, to allow space enough for the furnace man to get his arm in for lining the door, and the space at top is afterwards closed with bricks. This mode of closing is adopted for cupolas working with a pressure of blast from 4 to 7 inches of water; but where the blast is stronger a wall of coke is first built up inside the melting chamber C, and wetted; and the door being shut and secured with wedges, the space between the door and the wall of coke is then filled with ordinary foundry sand, rammed in.

The amount of filling that is put in for starting the cupola varies with the size and the quantity of melted metal that the hearth is intended to contain at once; but the amount is always much less than is usually employed in other cupolas. One of these cupolas, capable of melting 3 tons of iron per hour, requires a filling of 2¾ cwt. of coke for starting it, or 3¾ cwt. when it is intended to keep the whole of the metal in the hearth, to be tapped all at once. Upon this filling a charge of 8 cwt. of iron is added from the top of the cupola shaft, and then about ½ cwt. of coke, and again a charge of 8 cwt. of iron, followed by ½ cwt. of coke, and the same in succession until the whole charge is put in, filling up the shaft A to the top, as shown in Fig. 2. After the casting, a certain quantity of the coke is drawn out unconsumed. The average quantity of coke consumed is 1½ cwt. or 168 lbs. per ton of iron melted, when only 3 tons are melted in each charge; and the consumption is 147 lbs. per ton when charges of 6 tons are melted, and 140 lbs. per ton with heavier charges.

The above description of this German cupola was given to the Institution of Mechanical Engineers in 1868, when it was also stated that the metal melted was very clean and fluid. It does not appear,

however, to have come much into use in England, and recent German examples are considerably modified, being circular in section and having a chamber arranged where the breast is placed in Fig. 2, this chamber being at a lower level, and practically acting as a collecting ladle, the metal being run from it through a tap-hole in the ordinary way.

The Mackenzie cupola, Fig. 1, Plate V, is largely used in the United States. It is generally elliptical in plan, and the blast, instead of being supplied through tuyeres, is admitted through an opening which extends completely round the bottom part of the cupola. The blast is led into a chamber surrounding the boshes of the cupola, and from thence it escapes through the annular opening into the cupola. The cupola is fitted with a drop bottom, which arrangement is almost universally adopted in the United States.

When first started it is necessary to employ a very light pressure of blast, but as the melting proceeds the pressure is brought up to 2½ lbs. per square inch. The blast is generally applied about forty minutes after the fire is lit, and iron begins to run about twenty minutes afterwards.

American cupolas as a rule are large in diameter, which is an essential feature when anthracite, the fuel most common in America, is used. An arrangement often adopted is to have the sides parallel, but with a convex-shaped belt of the same material as the lining arranged just above the tuyeres, this belt effecting the same object, in our opinion but imperfectly, as the boshes in such forms as those of Ireland or Voisins.

The two Mackenzie cupolas employed at the Altoona Wheel Foundry, United States, which is illustrated amongst our plates, are nearly rectangular in section, one measuring 7 feet 6 inches by 3 feet 6 inches at the boshes, and 8 feet 6 inches by 4 feet 6 inches at the largest part; the distance from the tuyeres to the charging level is 9 feet 6 inches. These tuyeres form the characteristic continuous opening 1½ inch wide, and extend round the cupola, at a height of 8 inches above the bottom when the latter is ready for charging. No flue is employed in melting the charges, and no provision is made for tapping the slag. The average quantity of metal that can be run from each of these cupolas before the tuyeres become so clogged as to impair the working, is 63,000 lbs. The

charging stage of these cupolas is placed 15 feet 6 inches above the floor level, and is formed of iron plates, the charges being raised by an hydraulic lift.

Ireland's cupola is built with boshes, and has a cavity of enlarged diameter below them, so as to give increased capacity for the liquid iron. In his first patent there are described two ranges of tuyeres, ordinary ones at the bottom, and smaller but more numerous tuyeres above the boshes, which latter it was proposed to supply with heated blast.

Fig. 1, Plate VII., is a section of one of the earlier forms of Ireland's cupolas. There are eight tuyeres in the upper row, 2 inches diameter at the nozzles, and three tuyeres in the lower row, which are 6 inches diameter inside. The two rows are 1 foot 7 inches apart from centre to centre in the cupola shown on Figs. 1, 2, 3, Plate 7, which is 21 feet high from the floor to the top, and 4 feet 1 inch diameter outside the iron casing.

Figs. 2, 3, and 4, Plate V., are vertical sections of three cupolas designed by Ireland, all of which worked very satisfactorily. It will be seen that the upper row of tuyeres have here been abandoned, while retaining the boshes, the general interior shape being much modified.

There were two tuyere holes to each cupola; the tuyere pipes were 2 inches in diameter, and were not allowed to enter the tuyere holes. The consumption of fuel was from three to three and a half hundredweight of Newcastle coke per ton of iron melted, when the cupolas were working short spells.

The principal dimensions were as follows:—

TABLE IV.—IRELAND'S CUPOLAS.

DIAMETERS.	Fig. 2.	Fig. 3.	Fig. 4.
At sole	2·6	2·9	3·6
At cylinder of boshes	1·7	2·0	2·9
Above the boshes	3·0	3·6	4·3
HEIGHTS.			
From sole to bottom of boshes	1·6	1·7	3·0
Height of cylinder of boshes	1·2	2·0	2·5
„ of jams of boshes	2·0	2·0	2·0
„ of cylinder above boshes ..	6·4	6·6	5·7
„ of chimneys above sill of charging door	12·0	12·0	14·0
„ of centre of tuyeres over sole	1·8	1·8	3·2

Ireland's directions for the management of each of the above cupolas were as follows:—

"The small cupola, Fig. 2, Plate V., must be filled with coke about half way into the boshing, and then put on about three handsfull of limestone. Then put on the pig metal across the centre of the furnace, with the ends of the pigs towards the tuyeres, piling up the sides with scrap, and cover the whole with coke. If the weight of metal be 20 cwt. put on 10 cwt. at a charge, proportioned, 7 cwt. of pig iron and 3 cwt. of scrap, and cover well with four riddles of coke. If the weight of iron be between 20 cwt. and 26 cwt., divide it into two equal charges, and put between each of the charges four riddles of coke. Put three handsfull of limestone between every charge. If the weight of metal be 30 cwt., or up to 40 cwt., divide it into three charges, and put on coke as above stated."

"The cupola, Fig. 3, is intended for castings up to 4 tons weight. It must be filled up 6 inches into the boshing with coke, then put on 15 cwt. of metal, 10 of pig and 5 of scrap, and cover with 1½ cwt. of coke. The second charge must be 15 cwt. of pig and 5 cwt. of scrap, which must be covered with 1½ cwt. of coke. The third charge may be increased to 22 cwt., the fourth to 24 cwt., and the fifth to 25 cwt., but it is best to keep the charges at 20 cwt. and 1½ cwt. coke. Put on four handsfull of lime between each charge. When the furnace is built take care that a slag hole is cut about 3 inches below the tuyere. The charges must be put on as described for the small furnace."

From the cupola, Fig. 4, a 12-ton casting may be obtained. Fill it up with good coke 8 inches into the boshing. Then put half a riddle of limestone. The first charge to be 20 cwt. of metal, pig and scrap, cover with 1½ cwt. of coke; the second charge 25 cwt. and 1½ cwt. of coke; the third and following charges in the same quantities, until the required weight of metal is in the cupola, adding the limestone between each charge. The best and cleanest iron should be first put into the furnace, and the worst and most rusty of the iron last. If the tuyeres get dark, prick them with a small bar at the sides, and by putting in a little coal they will keep bright and clear.

A pair of Ireland's cupolas, described by Mr. John Fernie in

1856, are shown in Figs. 1 and 2, Plate VI. Each furnace is capable of melting at the rate of 3 tons of iron an hour. The height from the door to the top is 27 feet, and from the floor to the level of the charging door K 12 feet 6 inches. The shell is parallel from the ground to the charging door, and thence it gradually tapers up to the top. The outside diameter is 4 feet 6 inches in the cylindrical part, and 2 feet 6 inches at the top. The inside diameter is 2 feet 6 inches at the bottom of the crucible, on the cupola hearth L, contracting to 2 feet 3 inches at the springing of the boshes M M, and 3 feet 9 inches from the boshes to the charging door, whence it tapers to 1 foot 9 inches at the top. The height of the crucible is 4 feet 3 inches, and of the boshes 1 foot 8 inches, and the height from the boshes to the charging door 6 feet 3 inches. From the top of the boshes to the top of the cupola the lining is formed of a single thickness of fire-bricks, which is quite sufficient, as practically there is found to be very little wear above the top of the boshes. The centre of the blast-hole N is 2 feet from the bottom of the cupola, and the hole is 9 inches in diameter, to admit a 7½-inch tuyere. O is a slag-hole, 5 inches in diameter, the top of which is level with the bottom of the tuyere hole. P is the tapping hole, which is made in the usual manner.

In charging the cupola in the morning a small fire is first made at the bottom as usual, and then 7 cwt. of coke is put in. The top of this should be carefully levelled, which is easily done in throwing in the last few skips. On the top of the coke 1 ton of iron is thrown in, the pigs being broken into three or four pieces each, which are thrown on with their length parallel to the direction of the blast, as shown in the plan, Fig. 1, leaving a space immediately over the tuyeres for the scraps that are to be melted. The next charge is 2 cwt. of coke, the top of which being levelled as before, 1 ton of iron is again thrown in, the pig ends lying in the direction of the blast, as in the first charge, and the scraps are added over the tuyeres. The next charge is 1½ cwt. of coke, and then 1 ton of iron, and these charges are repeated till sufficient metal has been laid on. The cupola is ready for blowing as soon as it is charged up to the door, as shown in the Figure; it

then contains 6 tons of metal and 15 cwt. of coke, or 2½ cwt. of coke per ton of iron.

The first charge in the afternoon is rather less than that in the morning. A portion of the coke used in the morning is saved, and the cupola being still warm less is required at starting. The first charge is 5 cwt. of coke, after which the charging is the same as in the morning, giving a consumption of about 2⅛ cwt. of coke per ton of iron. Hence the mean consumption is about 2⅓ cwt. of coke per ton of iron for the whole day. The charge of flux consists of ½ cwt. of Derbyshire spar, added on the top of the second and fifth charges of metal, the same being added at every third charge of metal afterwards. The slag-hole is kept open nearly all the time of blowing, and has a spout from it, running off into a small waggon.

The repairing of the cupola is done every other day. The brickwork just above the tuyeres becomes hollowed out by the action of the blast, and the cupolas are accordingly charged only every other day. When 24 tons of metal have been melted, amounting to two days' work, the repairs that are then ordinarily required take on an average twelve to twenty bricks, about ½ cwt. of fire-clay, and two or three hours' labour. The cupolas on this construction at the Britannia Foundry, where these two cupolas were erected, have given great satisfaction. They save nearly half the coke that was formerly burnt in the cupolas on the ordinary construction that were previously used in the same place. The bricks used are from Stourbridge, and the coke is from Elsecar.

The superiority of Ireland's cupola over the old construction consists in the shape of the interior, the height, and the *perfect system of charging*. Owing to the shape of the interior, the charges are kept up by the boshes M M alone, and as they gradually descend the incline they are melted; consequently the only portions of the lining of the cupola that are subject to wear are the boshes and the sides of the crucible. The advantage of the height of the new cupola is evident when comparing it with some of the old cupolas, in which the height from the ground to the charging door seldom exceeds 8 feet, and in many cases is not more than 6 feet, instead of 12 feet 6 inches, as in the new cupola; con-

sequently, a great portion of the heat is lost at the charging door which is here retained; and as all the heat has to pass up through the charges, the iron above is gradually warmed as it descends.

In 1866 the Bolton Steel and Iron Company employed two of Ireland's cupolas for melting the iron for their large anvil block, which weighs 205 tons. The external diameter of each of these cupolas was 7 feet, the diameter at the boshes 3 feet 9 inches, and 5 feet at the greatest diameter above and below. The blast was supplied by blast cylinders at a pressure of 14 inches of water, and was delivered into the cupola through two ranges of tuyeres, sixteen tuyeres in the upper range, 3 inches diameter; four in the lower range, 8 inches diameter.

Each cupola was enclosed in a casing of boiler plate, with an external air-belt and blast-pipes.

To produce the anvil block, 220 tons of metal were melted, of which 8 tons consisted of lumps of Bessemer steel, and the time occupied from putting on the blast, for melting the metal, and filling in the mould was $10\frac{3}{4}$ hours. The consumption of coke per ton of metal melted was only 1 cwt. 1 qr.—a very remarkable result, due no doubt, in a great measure, to the height of the cupola, which enabled the heat and gases to be reabsorbed by the fuel and iron as they passed upwards through them out of the cupola. This points to the great value of tall cupolas, with the use of powerful and heated blast, and the reduction of diameter at the tuyere level.

Woodward's steam-jet cupola is worked by means of an induced current caused by a steam-jet blowing up the chimney of the cupola, instead of by blast forced in below. It is asserted by those interested in this cupola that it effects a great saving in fuel over the ordinary fan-blast cupolas, and it seems tolerably certain that it is at least as economical as the best ordinary furnaces where fans are employed, with the additional merit of great simplicity.

The steam required to create the draught is only equal in quantity to what would be consumed by an engine for driving a fan of sufficient power to work an ordinary cupola of the same size. The consumption of coke in melting 1 ton of iron is put at $1\frac{1}{4}$ cwt., a very low rate of fuel, which has, however, been also obtained by other cupolas of good design and properly worked. There is

besides a saving in first cost of engine and fan, and of all their wear, tear, repairs, and renewals. There are several different modes of applying the steam-jet, but the principle will be at once understood from Fig. 4, Plate VII., and Plate VIII.

Fig. 4, Plate VII., has a simple plate-iron cover, up which the steam jet A forces a blast. Just beneath the steam-pipe is the charging door B with a movable cover.

The cupola is shown in position just outside the foundry, with the metal spout passing into it through an opening in the wall. The steam is brought to the top of the cupola from a boiler in steam-pipes, properly covered to prevent condensation. The jet is a simple nozzle, similar to those used in locomotive chimneys, as there is found to be no necessity in practice to regulate the draught by any alteration in the size of the jet.

The air is drawn into the bottom of the cupola through openings placed radially at two different levels. In the lower row there are four such openings, and in the upper row there are eight. Each of these air-inlets has a cover which can be closed from the outside.

The charges are lifted to the door B at the top, and charging can be continued during the blowing. If, however, it is desired to use the cupola for continuous working, it is preferred to have a feeding hopper, with a sliding door, to be worked by a lever, as shown in the second arrangement, Plate VIII. The furnace is charged as usual with alternate layers of coke and iron, all the air-passages being then opened. When the furnace is at work the draught has to be regulated by the furnace man, and care must be taken to close any air-inlet near which iron is seen to accumulate in a semi-liquid state; the temperature near that spot will soon rise to the proper degree to cause the iron to run freely, when the air-inlet may be reopened.

In Plate VIII. the steam is arranged to blow through a side flue into the chimney. The feeding hopper to the furnace *a* is represented open, that of *b* is shut. There are eight air-inlet holes in the upper row, and three in the lower row.

Heaton's cupola is constructed by building a tall stack on the basis of a cupola, and providing the latter with two rows of large tuyeres; the heat and draught are maintained simply by the

ascensive power of the hot air passing up from the cupola and stack or chimney. This cupola can scarcely be found advantageous in intermittent working, as it has to be carefully and slowly heated up and charged when first started, but for continuous working it might answer.

We are indebted to Messrs. Aitken, Jessop, and Co., of London, who are the introducers of it into this country, for the particulars of Voisin's cupola, which is fully illustrated in Figs. 1 to 6, Plate X. It is constructed of boiler plate—in thick double riveted, in this instance, and lined with fire-brick made to the shape of the interior. The bottom is arranged to drop after the American plan, sufficient space being allowed beneath to accommodate a truck or trolly for conveying away the broken bottom and contents remaining when the furnace is "drawn." The blast is supplied from a belt completely surrounding the cylinder of the boshes, and from this belt two sets of tuyeres, four in each set, deliver the necessary supply of air. It will be seen, Figs. 5 and 6, that the lower set are arranged opposite and at right angles to the main, while the upper set are diagonal to it. The inventor claims through this arrangement of the tuyeres, that the gases being burnt in the interior of the cupola, create a second zone of fusion with those gases alone. In other words, the second set of tuyeres obviate to some extent the evil effect of the formation of carbonic oxide. Voisin's cupola has certainly been very successful, and this more so, we are inclined to think, owing to the careful proportioning of every part given to it by the inventor.

Fig. 1, Plate XI., is a vertical section, Fig. 2, a plan, and Fig. 3 details of a cupola used at the Polytechnic School, at Angers, France. It is the Voisin's system, and the results obtained in work are as follows:—In charging the cupola 330 lbs. of coke and 1100 lbs. of iron are used. The subsequent charges of coke weigh about 55 lbs. The four lower tuyeres are fitted with sight-holes of coloured glass or talc, fixed as shown; the four upper tuyeres have a diameter of $2\frac{1}{16}$ inches, and a uniform distance of 25 inches. The rate of melting is little less than 4 tons per hour, the pressure of blast reaching 8·66 inches of water. The shell of the cupola is of cast iron. As to the cost of working, in twenty-two meltings 51 tons of iron were melted by rather less

than $4\frac{1}{3}$ tons of coke. The coke used is of inferior quality, manufactured at the school. This cupola has been at work for four years. Fig. 1 shows clearly the constructing of the charging floor, and also the arrangement of the main trains and stop-valves; Fig. 3 the mode of construction of the sight-holes.

A portable cupola with its fan is shown in elevation, Fig. 1, and in plan, Fig. 2, Plate XII., it is formed of a cylinder A A, of sheet iron $\frac{1}{16}$ of an inch thick, 2 feet 3 inches in diameter, and 4 feet 6 inches high, lined with fire-bricks and clay B B, in the usual manner, 4 inches thick.

The cupola weighs about 6 cwt., and is easily lifted by the workmen on to a trolly and taken to the place required, when it is lifted off and placed on a temporary staging.

The cupola has a belt or air-chamber at C C, into which passes the air from the fan, and it has four tuyeres of 2 inches orifice to admit the air to the fire. The yield of metal from so small a cupola was great; as much as $3\frac{1}{2}$ tons have been run down in seven hours by two men turning the handles of the fan, and nearly $4\frac{1}{2}$ tons by the use of the engine in the same time.

Numerous other forms of portable cupolas are known, but none of them appear to be as efficient and simple as that illustrated, which was employed some years since melting metal for a special purpose on one of the large English railway lines.

Immediately over every cupola should be a hood, which may be supported by a ring of cast iron on pillars resting on the top plate of the cupola, the hood itself being of sheet iron or built of good red brick set in fire-clay, with a considerable taper, and having hoop-iron bands at intervals of from 2 to 3 feet the whole way up.

The common cupola, for the height of about one diameter, should have its sides built parallel, after which they may gently taper inwards to the height where the top plate receives the pillars for supporting the hood, the whole being lined with the best fire-brick, and all the spaces between the pillars and the hood ring are also to be filled in with fire-brick, except the opening, which is to be left between two of the pillars for the feeding aperture.

The cupola may also be lined with a mixture of fire-clay and river sand, firmly rammed in, and slowly dried; or with road mud,

when obtained from a road macadamized with flint or hard sandstone; but the latter must not be used if it contains any iron or lime, and is not to be recommended as very reliable. The lining should be at least 9 inches thick, and may be thicker if made of fire-brick. The bricks must be set in fire-clay mortar, consisting of refractory sand, and as much fire-clay as is needed to hold the sand together.

For small cupolas a lining of well-rammed Gannister may be used, or washed scrapings from off flint roads, if in a clay district.

The material was at one time commonly applied by ramming it down between the inside of the cupola and the outside of a wooden block of the same shape as the cupola, but so much smaller as to leave the desired space for the lining. The wooden block must be so made as to be easily taken to pieces to be removed, on the principle of a bootmaker's last. This plan is still occasionally practised, especially in France. Great care is required in drying this lining, as it is difficult to prevent unequal drying, when parts of the lining will probably become detached the first time it is put in blast.

It is therefore decidedly preferable to use special fire-bricks, or "lumps" for the lining, especially of large cupolas, although as a refractory material, gannister is scarcely to be surpassed, consisting of nearly pure silica, with a little oxide of iron and alumina.

In the choice of fire-bricks care must be taken not to rely too implicitly upon a mere analysis of their constituents, as a good deal depends upon aggregation of the particles; for two clays may resemble one another very closely on a comparison of their analyses, and yet one may be very fusible whilst the other is extremely refractory.

The fire-brick lining, except for portables, should never be less than 9 inches thick, the bricks all being laid as "headers" with fire-clay joints not exceeding about one quarter of an inch in thickness.

The fire-clay used for this purpose, and also for backing up the brickwork to the casing of the cupola, should be the same clay as that from which the fire-bricks have themselves been made, so that when at high temperature there shall be no tendency to any

chemical reaction, such as might be caused by only a slight variation in the constituents of the clay.

For the same reason it is necessary that the fire-clay be kept in a covered store, protected from dirt, rusty borings, or other rubbish likely to injure its purity.

The damp, loamy sand used for the bottoms of cupolas should not contain much alumina, and should be rammed well down, especially where it touches the walls. It should be about 6 inches thick, at the outer edge, slightly hollowed towards the centre, and with a good fall towards the tap-hole.

When the cupola has a movable iron bottom, care must be taken not to put so little sand on it as to risk burning the trap away, whilst on the other hand if the bottom is too thick it will be more difficult to break down when it is wished to empty the cupola, especially if the sand contains a large percentage of clay tending to make it bake hard and solid.

The tuyeres for large cupolas may be protected from the heat to which they are exposed in the same manner as blast-furnace tuyeres, but the destructive action to which they are exposed is less than that which blast-furnace tuyeres have to bear, where they carry in highly heated blast into the furnace.

The usual method of protecting a tuyere is by keeping up a circulation of cold water round it, which is effected in a variety of ways, great care being necessary to prevent any leakage into the furnace, a source of much danger to the men.

Until recently all the tuyeres in use since the introduction of hot blast first necessitated a water tuyere may be classed under two heads, namely, the coiled tuyere and the water-jacketed tuyere.

The coiled tuyere is generally made of a coil of wrought-iron tube imbedded in the sides of a hollow case of cast iron. Sometimes the coils are wound close at the nose of the tuyere, in order more effectually to prevent the cast iron from burning; and sometimes the tuyere itself is formed entirely of a coil of tube, closely wound from end to end.

The water-jacketed tuyere is generally made of wrought iron, and consists of two conical tubes of different diameter, connected at each end by rings of wrought iron welded in, so forming a space

between the two concentric walls of the tuyere, which is filled with water supplied under pressure, and generally brought in through a feed-pipe at or near the bottom of the tuyere, and allowed to escape through a second pipe in the upper side.

Phosphor-bronze tuyeres are generally fixed in a cast-iron casing or box, beyond which they project into the furnace for the greater part of their length, and they are so arranged that they can be turned round in the cast-iron plate or box in order to expose a different side of the tuyere to the action of the materials in the furnace. Greater durability is claimed for phosphor-bronze than for gun-metal or copper, but each metal possesses the same advantage of preventing adherence of slag, scoria, or iron to the nozzle of the tuyere, which is the only object to be gained by the use of copper or its alloys in preference to iron. Additional precautions as to water supply have to be taken where such metal is used; as, owing to the low temperature at which it melts, a copper tuyere may be more rapidly destroyed than an iron tuyere where any overheating is possible, but under favourable conditions both gun-metal, copper, and phosphor-bronze tuyeres have been found very durable, and the advantage gained by keeping the blast nozzle always clean and fully open is an important one.

The open spray-tuyere invented by F. H. Lloyd, Fig. 4, Plate III., consists of two concentric conical tubes, closed at the nozzle but open at the rear end. The water supply is connected in the usual manner with a flexible hose, and various systems of spray-pipes are used to suit various shapes of tuyeres and various conditions of water supply. The spray-pipes are made either of wrought iron, brass, or copper, and a sufficient amount of water is allowed to escape through small holes or slits in the spray-pipes to protect every part of the tuyere casing which is exposed to the heat of the furnace. The spray or jet of water from each hole in the spray-pipe spreads over a considerable surface, and a small number of holes is, if they are properly placed, sufficient to keep the whole interior surface of the tuyere casing constantly wet. Scarcely any steam is visible, and the waste water passes away, after cooling the tuyere, at a temperature little exceeding that at which it entered, unless a large portion of the tuyere is exposed to violent heat, in which case the temperature of the waste water is

certainly no greater than it would be from a tuyere of the old system placed under the same conditions. The spray is principally directed to the loose end of the tuyere and beats back to some extent on the top and sides, which are also protected by a sufficient number of additional sprays from holes drilled in the spray-pipes. The water falls round the sides and end of the tuyere and escapes from the back through the waste-water pipe as shown in the drawing, Fig. 4.

The number and position of the tuyere-holes very much depend upon the size of the cupola, the quality of coke, and the nature of the pig to be employed.

For some small cupolas, only one tuyere is used, which is placed at the back of the cupola, about 15 inches above the bottom. According as the diameter of the cupola is increased, so must the number of tuyeres be increased around it in the same horizontal plane so as to generate a uniform heat at all points in the furnace. If the cupola is of a comparatively small diameter several tiers of tuyere-holes should be arranged, one above the other, 8 or 10 inches apart, so that if it is required to melt a large quantity of iron at once, the tuyeres can be raised from the lowest range of tuyere-holes to the range next above it, the first range being plugged with fire-clay; when the iron is melted to the level of the second range, it is also stopped up, and the next higher put in operation.

But the process is much simplified by having a cupola of large diameter capable of holding a considerable quantity of liquid iron with but a small rise in height inside. There is then no necessity for more than two or three tiers of tuyere-holes. Of course, these observations do not apply to cupolas furnished with a belt, and only to such forms as are shown in Plates III. and IV.

Assuming a cupola to be capable of yielding 2 tons of liquid iron per hour, when in good blast, with one shift of the tuyeres, and that a 10-ton casting is required, the process would be as follows:—The first 2 tons would be tapped and run into the ladle, when the tapping hole would be closed, and blast again put on. The metal in the ladle would be covered with about an inch of charcoal dust; at the end of the hour the second tapping would take place, and melting again be resumed, until the five successive

tappings had been taken from the cupola, and the ladle contained the required quantity of 10 tons of iron, of a sufficiently high temperature and liquidity for large castings. For although the first metal that is tapped is somewhat cooled by contact with the cold ladle, and has to remain in it for upwards of four hours, yet each successive tapping is of a higher temperature than the preceding one, as the cupola gets hotter the longer it is at work, and the metal in the ladle is therefore maintained at a sufficiently high temperature.

It is obvious that if still larger castings are required, the metal can be accumulated in this way in ladles from two or more large cupolas, without the inconveniences of the shifting tuyeres, and the dangers arising from the pressure of great heads of metal necessarily incurred with cupolas of small diameter. There is, however, a limit of time in this intermittent process. In the first place, it is obvious that the metal must not be kept too long in the ladle before pouring; and in the next place, slag will accumulate in the cupola, and the yield of liquid iron per hour will be considerably decreased.

The air-main from the fan to the cupola is provided with one or two upright cast-iron pipes, which may either lead into another pipe surrounding the cupola, or be connected directly to the tuyeres.

In the first case the pipe surrounding the cupola has as many openings in it as there are tuyeres, and the nozzles of the tuyeres are attached to these openings. In the second case, where the tuyere nozzles are fixed on the upright blast-pipes, it is obvious, there must be as many upright pipes leading from the blast-main as there are tuyeres in the circumference of the cupola. These upright pipes should be turned outside for several feet, so that the tuyere-pipe can slide up and down it, so as to direct the blast into any one of the ranges of tuyere-holes as desired. The nozzles of the tuyeres are curved, so that when directed towards the cupola, they reach within an inch of the tuyere-holes, which there is no necessity for them to enter. The nozzles are generally sheet-iron tapered pipes, but are sometimes, and preferably, made of copper. In this arrangement the sliding pipe is fixed on the rising main at the desired height by a screw, and the nozzle

directed towards the tuyere-hole. If it is necessary to stop the blast, the screw is slackened and the pipe is turned, so as to direct the sliding nozzle away from the cupola, or the pipe is raised so as to present the nozzle to the next tuyere-hole. In arranging the air-main from the fan to the cupolas, by-pass valves should be so arranged that the blast can be shut off from any one cupola at any moment, without interfering with the supply of blast going to the others. In some forms of those furnaces provided with a belt, means are provided for separating the blast of the upper or lower row of tuyeres, or again from any particular pair of tuyeres, at will.

It is sometimes advisable to have a movable iron screen to protect the furnace men from the heat and smoke which issue from the feeding mouth during windy weather, but however easily these refinements can be made to work, the men seldom avail themselves of their use; besides, when a cupola is in blast, the furnace man has to keep a sharp eye upon the feeding mouth, to regulate the supply of materials, the proper combustion, and the uniform descent of the iron and fuel.

One of the most important modifications of late in the construction of the cupola has been the introduction of the falling hinged trap-door, shown in Voisin's furnace, Plate X., to allow of the whole contents to be dropped into a pit beneath the cupola, after tapping; by this arrangement the cupola is much more easily and quickly emptied when "done work," than by the old and fatiguing process of "raking out." When this arrangement can be adopted, that is, when there is the power to have a clear gangway left beneath the range of cupolas, it is necessary to pay great attention to the proper arrangement and strength of the supports for the cupolas.

A brick tunnel for the blast-pipes should be built behind the cupolas, the back and fronts of the cupolas should be carried on strong brick piers, with a vaulted brick passage passing directly under the cupolas, leaving the central portion of the bottom of each cupola quite free. Light iron trucks running on rails laid in this passage will be brought under any cupola that is to be emptied, will receive its load of coke and slag, and will be run away to the pit, where its contents will be emptied and quenched, preferably by a hose and jet, so as to avoid unnecessarily saturating the coke, as

is done when it is bodily cast into water troughs to be cooled, and when the coke is again used, the whole of that water has to be evaporated.

The mode of forming the trap-door is as follows:—The brick lining of the cupola rests upon a strong flanged iron ring, which is supported by cast-iron columns resting on the brick piers. The central circular aperture, as large as the interior of the cupola left by this ring, is closed by a wrought-iron trap-door hinged to the back of the cupola, and secured in its place by bolts, which can be easily drawn by a sharp blow, so as to let the trap fall vertically, when the whole of the contents of the cupola will be received in the trucks beneath.

The trap being left open, allows a current of cold air to pass up through the cupola and chimney, so that in the course of about twelve hours the lining has cooled down sufficiently to allow the men to repair the lining, and put in a fresh bottom of loamy sand.

In places where this system cannot be adopted, and the raking out of the cupola from the front, on the old plan, is to be used, the breast opening should be left about 2 feet square, to be closed by a falling apron of wrought iron, having a small opening left at its lower edge for the tapping hole, 4 or 5 inches wide, by 6 or 7 inches high.

When the cupola is to be charged, the apron is left full open; firewood and coke are charged into the cupola and ignited, and when the coke is well alight, a quantity of loamy sand is shovelled into the breast opening until it is quite full, and is tightly rammed in; the apron is then brought down forcibly through the superfluous sand; or the apron may be closed before the fire is lit, and the furnace man, when putting in the sand bottom, must also fill up the breast opening with the same material, solidly to the iron apron, and to the full thickness of the brick lining of the cupola.

In either case care must be taken to preserve the tapping hole, made as before described, open, which must be on the level of the shoot outside. This tapping hole is, of course, placed so as to come within the orifice left on the breast opening.

When the metal commences to flow, the tap-hole is closed in the usual way.

When it is desired to take out cinder and slag from the cupola, after tapping, the apron is removed, and part of the sand breast broken away, and the furnace easily cleared within.

In the disposition of a range of cupolas, attention should be particularly directed to placing them conveniently for access with the raw materials, all of which it must be remembered have to pass along the charging platform to the furnace mouth, and are much more bulky and weighty than the output of castings.

It is advisable to keep the cupolas, the tapping floor, and the charging platforms, in a separate building from the rest of the foundry, but communicating with it, and to have it covered with a light corrugated iron roof, but provided with means of obtaining ample ventilation.

The charging platform must be strong enough to bear the passage of the heavy loads of materials passing over it, and of sufficient area to allow of the separate stacking of the coke, limestone, pig and scrap iron employed in each cupola: also for the fire-brick and fire-clay required in repairs and lining.

There are various methods employed for raising the materials on to the charging platform, the most costly and inconvenient of all being manual labour, except in cases of very small foundries.

A travelling steam-crane which can be moved to serve any one of the range of cupolas, or a hydraulic lift, such as that shown on Plate VI., which will hoist a truck load of coke or iron from the ground level to the platform, are the arrangements employed in the best works; all materials reaching the charging platform pass over a weighbridge, and the furnace man in charge has to keep an account of these deliveries.

In charging coke into the cupola, a wide steel fork, with about eight round tines or prongs will be found more convenient and economical than the common shovel generally used, as the coke will be less broken, whilst the breeze and dirt will not be thrown into the cupola as with the shovel.

In cases where the coke is very friable, or has had to bear much carriage, the percentage of breeze becomes a material element in the cost of fuel; if thrown into the cupola much of it is immediately blown away, whilst any dirt put in with it of course represents so much the more slag to be dealt with.

The breeze, if kept clean, can be ground into coke-dust to be used by the moulders.

Supposing the cupola to be cool, but in good working order as to lining, tuyeres, &c., the falling iron door at the bottom, if the cupola is provided with one, must be closed, and securely fastened in its place, and well covered with sand; moulding sand is used when only a small quantity of iron is to be smelted; if a large quantity of melted metal is required, a more refractory sand is desirable. A wood fire is then lit in the cupola, upon which coke, coal, or charcoal is placed, the tap-hole being left open to supply air to support the combustion, the tuyeres being also left open. The cupola is then filled with fuel, which is kept in brisk combustion. It requires several hours to heat the furnace for blast, which is not laid on until the flame appears on the top of the fuel. When the furnace is thoroughly heated, the nozzles are put in, and the fan, or blower, is put to work. Before putting on the blast, however, the large tap-hole must be closed with moulding sand, or good fire-proof clay and sand mixed, leaving a small hole at the bottom, which serves as the tap-hole for the iron. This should be about 2 inches diameter, and is formed by placing a tapered iron bar in the place where the hole is to be, ramming the sand tightly around it, and removing it as soon as the hole is properly and securely moulded. When the blast is put on it will drive a flame through the tap-hole, as well as out of the top of the cupola. The tap-hole is left open to dry the fresh loam and sand, and also so that its sides may be glazed or vitrified by the heat, so as to resist the friction of the tapping bar; the heat also serves to glaze the lining of the cupola in those parts which have been mended with fire-clay since the last smelting.

When the cupola is intended to hold a large quantity of iron, the large tapping hole should be covered with an iron plate, securely fastened to the iron casing, leaving only the small tap-hole open.

Commence charging iron as soon as the lower parts of the furnace show a white heat, which is best known by the colour of the flame issuing from the tap-hole, it being at first a light blue, but afterwards becoming of a whitish colour. About ten minutes after charging the iron, the melted metal appears at the tap-hole, which must then be closed by a stopper made of loam, which has been

worked by hand to a proper consistence; a round ball of this is placed on a disc of iron at the end of a wooden rod, and is forced into the tap-hole; this is also done when it is wished to stop a tapping out with the bott or bod stick, as it is called, but is then a more difficult operation, as the molten iron frequently squirts out past the bott stick whilst the men are trying to apply the plug.

Pig iron is broken into pieces or from 10 to 15 inches in length before it is charged into the cupola. This is a very laborious operation, especially in the case of tough pig iron. The first breaking is generally accomplished by throwing the pig down heavily upon a piece of old iron fixed in the ground, after which it is broken up still smaller with a sledge-hammer.

This work is now very often performed by an adaptation of Blake's, or some other, stone crusher.

From 10 to 12 lbs. of fuel are charged for every 100 lbs. of iron, but this quantity varies, depending much upon the nature of the fuel, of the iron to be melted, and upon the size and construction of the cupola. Along with the coke and iron, limestone must be put in, broken up into pieces about 2 inches cube, or oyster shells, in quantities varying from 2 to 5 per cent. according to the nature of the fuel and iron. Too much limestone, as well as too little, causes the iron to become white, to lose some of its carbon, and, in many cases, its strength and softness are greatly impaired.

The limestone, when used, is commonly introduced into the cupola after the first charge of metal. It is intended to act as a flux, and combine with any earthy matters that may be present in the metal and coke. With these it forms a glassy compound, and, by this means, the iron is freed from such impurities as it falls to the bottom. The slag, as it is termed, floats on the surface of the iron collected at the bottom, and frequently makes its appearance at the tuyeres in a solid state.

The cupola should be kept full whilst in blast, or at least so long as iron is melted, by alternate charges of iron, fuel, and limestone. Fuel is generally put on first, then iron, and, lastly, the limestone, and the charging continued without intermission, until all the iron required at that time is melted, when the charges are stopped. The blast is, however, kept on until all the iron has been

tapped. As a matter of experience it has been found that the interior form of furnaces greatly affects the condition of the metal, and thus influences its applicability to certain uses; thus cupolas which are larger in diameter at the bottom than at the top work hotter than those with parallel sides, and also last longer, as the melted iron, which is apt to cut the fire-brick, then sinks more through the materials in the body of the cupola than it does in cupolas with parallel sides. The amount of taper to be given to the lining depends upon the size of the cupola; a large one will bear more taper than a narrow one.

If it is intended to melt different qualities of iron in the same heat, a thick layer of fuel should be placed between the various brands, so as to allow of the extraction of all the iron which was first charged, before the second appears at the bottom.

In such cases it is preferable to first melt the grey iron, or that iron which is to make soft castings, and white or hard iron afterwards.

When as much iron is melted as is required, the clay plug of the tap-hole is pierced by a sharp steel-pointed bar, or iron rod driven by a hammer, and the metal run into pots, or it is run directly into the mould by means of gutters moulded in the sand of the floor. Between each successive tapping of the iron, the tap-hole is closed, and more iron is allowed to accumulate in the bottom of the cupola.

Where more iron than the furnace will hold is required for one casting a portion of it is poured into a large ladle, which is kept until another charge is ready, and this process, as before remarked, may be so managed as to obtain good-sized castings from a small cupola.

Less coke is consumed when the fusion is pushed more rapidly to collect a greater quantity of metal for heavy casting, as the iron required besides is not so hot as for smaller castings. About one-half more coke, on the contrary, is consumed in melting metal for hollow ware, and ornamental work, as these thin, straggling castings require metal at a much higher degree of heat than the larger; and were such metal suffered to remain long in the bottom of the furnace, it would run a risk of getting too cold to afford sharp impressions of the moulds.

The greatest source of waste, however, occurs when iron is taken from the same furnace at one time for light, thin goods and for heavy work. For as iron becomes less fluid the lower its temperature falls, it may be at first at such a temperature as will be suitable for the former kind of goods, while iron at a much lower one would be suitable for heavier casts. We may observe that when iron is drawn too hot for such a purpose as the latter, it must be allowed to cool before being poured, and the cooling is quickened by the introduction of scraps into the melted mass.

In large foundries there are generally three men engaged in conducting the business of a cupola; one acts as charger, another breaks the pigs into manageable pieces, and deposits them, with the scraps of preceding meltings, on the platform erected for the accommodation of the charger, the third waits at the tapping hole, and supplies the workmen with the metal as they apply for it.

When the work of the cupola is over, the workmen commence to clear it out. To this end they break down the temporary clay work that narrows up the tapping door to one small hole. Having cleared this away, a plate-iron fence is set up opposite the door behind which the workman stands and over which he shoots a long rod, kneed at the end, into the furnace to loosen the contents, consisting of refuse coke and clay, and drags them out while yet hot; for, if suffered to remain till cold, they would be congealed into one compact mass. This operation is much more easily performed in cases where the cupola is built with a movable bottom, as has already been described, as it is a very slow and laborious task to be done with the raking bar.

W. Hackney has described a small foundry cupola which with

1 lb. good Welsh coke melts 10 lbs. iron,
1 lb. anthracite „ „ 16 lbs. „

or 224 lbs. and 140 lbs. per ton respectively. In the north of England the amount of coke to a ton of iron in the cupola rarely exceeds 120 lbs., and is even brought down to 1 cwt. per ton.

Of course in large foundries economy in coke is important, especially as the less fuel can be used, the quicker the metal comes down. It must be noticed, however, that if the percentage of the fuel is too much reduced, the furnace will scaffold.

The quantity of coke consumed depends not only upon the quality of the coke itself, but also of the iron to be melted. Thus No. 1 hematite or cold-blast iron requires much more coke than Scotch or Cleveland. Anthracite coke, which is harder and denser than any other coke, requires a stronger pressure of blast for its effective combustion, and in such cases a blower is to be preferred to a fan, as giving a stronger and more effective blast. Another example is that of a cupola melting 1 ton of iron, with 126 lbs. anthracite coke; the iron consisting of No. 1 Scotch, No. 1 hematite, and old cast scrap in equal proportions—the blast given by a 24-inch diameter Shiele's fan running at 1700 revolutions per minute.

According to experiments of Dulong, 1 lb. of carbon combining with the necessary quantity of oxygen to form carbonic acid, developes 12,906 units of heat. The specific heat of cast iron being about 13, the melting point 2190°, and the coke containing 82 per cent. of carbon, then to heat a ton of cast iron ot a temperature of say 40° to a temperature of 2190°, would require

$$2190 - 40 = \frac{\overset{\text{heat}}{2150} \times \overset{\text{iron}}{2240} \times \overset{\text{sp. heat}}{\cdot 13}}{12906 \times \cdot 82} = 59 \cdot 1 \text{ lbs. coke.}$$

This is supposing that the whole of the carbon is converted into carbonic acid, but if by any means carbonic oxide is formed, a very different result is obtained; then 1 lb. ot carbon burning to carbonic oxide only evolves 4453 units of heat. It, however, by admitting air above the zone where the oxide is formed, we recover 4478 units, this + 4453 gives 8931, which is a little over two-thirds of the available heat to be got out of 1 lb. of carbon, allowing 10 per cent. for moisture in the coke, 10 per cent. for radiation, and 20 per cent. for loss of heat passing off at the top of the cupola, or 40 per cent. in all; the amount of coke per ton of metal should not exceed 112 lbs., although the actual consumption is, as we have shown, usually much higher.

It is absolutely necessary that the furnace should be kept in good repair, so as to preserve its shape, and the charges should also be made level and uniform in thickness as well as being carefully weighed. Every care in this respect must be insisted upon, as

it is absurd to expect anything but wasteful results unless each charge bears its proper relation to the preceding, which can only be the case by constantly using the weighing machine.

Both time and fuel are no doubt economized by the use of hot blast supplied to the cupola, but such economy would seem to be very small unless the temperature of the air can be brought up to from 700° to 1000°, although it is well known that with blast-furnaces an appreciable saving of fuel is obtained for every increase in the temperature of the blast supplied. But in that class of work the furnaces are so large, and the fuel consumed is so enormous in quantity, that even a small percentage saved amounts to some considerable gain at the end of the year; this is shown by the fact that old blast heating stoves which gave a temperature of about 500°, were generally replaced a few years since by improved cast-iron-pipe stoves, which could be worked up to or a little beyond 800°; these in their turn are being rapidly swept away in England, America, France, and Belgium, to be replaced by fire-brick stoves, with which the blast can be heated to about 1200° or 1400° Fahr.

It must be remembered, however, that to produce a ton of pig iron from the ironstone requires a consumption of 20 to 25 cwt. of coke, sometimes even more, and consequently when it is clearly seen that by adopting fire-brick stoves to obtain a high temperature, a saving of at least 5 cwt. of coke is effected for every ton of pig produced, an ironmaster can at once appreciate the fact that such appliances will very soon pay for themselves.

Unfortunately for the cupola its case is by no means so clear. In the first place, only pig iron is melted in it, and that generally not in very large quantities at a time, and most cupolas are only worked intermittently. The consumption of fuel for the work done is not very large, seldom exceeding 2 cwt. of coke per ton of iron brought down, consequently the general feeling appears to be to construct cupolas of the best known form, but not to adopt costly appliances for saving fuel, as they involve complication, are neither liked nor understood by the men, and even if successful make little alteration in the profit of the concern. Such reasoning is very obstructive of scientific improvement, but may be very good practical wisdom.

Notwithstanding this *laissez aller* principle, there have been

many attempts to heat up the blast supplied to cupolas, but in most cases failure has occurred from the difficulty of obtaining a *really high* temperature.

It has been proposed to surround the cupola with a jacket; others have placed piles of air pipes and passages over the cupola mouth to abstract the heat from the waste products of combustion, but in such arrangements the iron exposed to the heat will not long stand a *high* temperature without warping and leaking, and a low temperature, as before remarked, is of no practical utility.

In country works there are times when a small quantity of metal only is required to be melted, much below the usual burden of the cupola, and if for this small cast of metal it is necessary to work through with a full charge for the cupola, much fuel is unnecessarily burnt, and much time lost.

One remedy for this evil as practised in France consists in building a cupola rather large in diameter, and lining it inside with damp, loamy sand, rammed hard into place round a number of wooden cores, which are afterwards removed.

This arrangement gives the power of varying the internal capacity and shape of the cupola to a large extent, at a comparatively small cost, and with no very great delay.

In the United States pulverized coal and fine slack have been used in cupolas. The practicability of this utilization of a comparatively waste product was discovered in the following manner. There had been some trouble through scaffolding in the cupola, and to melt down the "Salamander," the manager withdrew the tuyere-pipes, rammed in a lot of small coal through the tuyere-holes, and again put on the blast. The scaffolding was removed in a very short time, and the work proceeded as usual. The blast-pipe was then perforated, and a small quantity of fine coal was supplied to the cupola through the tuyeres, which it was found not only prevented scaffolding, but caused the cupola to work much more rapidly. The great waste in melting iron in a cupola usually occurs at the zone of the tuyeres, on account of the large quantity of air blown in, and the absence of carbonic oxide at that point. What little carbon the air comes in contact with at this point forms carbonic acid, which is almost as destructive to the iron as free oxygen.

The principal waste of the metal occurs after its fusion and in its passage through this carbonic acid and atmosphere.

By the injection of the fine coal with the blast its combustion is secured at the zone of the tuyeres, producing carbonic oxide, and thus preventing the oxidation of the descending metal.

Beyond saving the waste of iron by this improvement, a much larger percentage of the carbon which the pig contains is transmitted to the converter, an advantage which would also be of great value in all cupolas for melting iron for castings, as the chief difficulty in that line is that the carbon is burnt out of the metal; the metal thus prepared is also said to run more fluid, and to produce finer and tougher castings than that melted in the ordinary manner.

In concluding this chapter we wish to impress upon the foundry manager the importance of securing the good working of his cupolas by selecting the furnace men from among the most intelligent of his hands, for most of the trouble in the works has its origin at the furnace. If this is cobbled and not kept in every way as it should be, constant annoyance will be the result.

CHAPTER V.

FONDERIE À CALEBASSE.

Such is the title by which a number of small iron foundries are known in Belgium, having plant of the cheapest and simplest construction, and yet capable of turning out very creditable work on a small scale. Much ingenuity and skill are manifested in the arrangement and manipulation of the apparatus employed, and a short description of the *modus operandi* (in part obtained from Rivet's 'Encyclopædia') will serve to show that in certain cases a small iron foundry might be erected with comparatively little outlay, in colonies or other out-of-the-way localities; or for repairs, or works which were required to be cast *in situ*. In countries where waterfalls are available, the blowing power required can be obtained by means of the *tromb*, a simple apparatus well known in connection with the Catalan method of reducing iron ore on an open hearth.

Fig. 1, Plate XIII., shows a side view, and Fig. 2 a front view of the Fonderie à Calebasse, the remaining Figs. being of details referred to hereafter.

In most of the Belgian foundries where this system is employed the weight of metal required to be melted is very small in proportion to the number and value of the castings made, these for the most part consisting of articles whose chief cost is represented by the skilled labour employed in the moulding shop. Delicate and artistic castings for domestic or architectural requirements, and numbers of small pieces which are afterwards to be annealed, are thus produced.

For such purposes the calebasse possesses unquestionable advantages over the cupola, although, for any work requiring a considerable quantity of liquid iron, the cupola is decidedly more economical in consumption of fuel.

The calebasse, or furnace, may be likened to a small cyl ndrical cupola, divided horizontally in two parts, blown with one tuyere, and having no tapping hole.

The top half, which is usually made of stout plate iron, is designed to lift off from the bottom part. The lower part consists of a wrought or cast iron vessel, shaped like a ladle, and having strong bars and cross handles fixed to it as shown. This portion of the apparatus answers two purposes; it is first used as a crucible, and afterwards as the great ladle for the melted metal.

The calebasse is placed against a wall, something in the manner of a smith's hearth; over it is a hanging sheet-iron hood, leading the products of combustion to the fuel.

That part of the wall immediately behind the *calebasse* is faced with good fire-brick, and is pierced for the tuyere *a* to pass through. Two large fire-lumps project from the wall, and between these the calebasse is erected.

The upper portion is called *la tour*, the tower *b*, Figs. 5 and 6; *le creuset*, or crucible *c*, Figs. 3 and 4, is the lower part.

The tower is usually made o. strong wrought iron, with a riveted band at top and bottom; in plan it is of a horse-shoe shape, the open side being that which is placed against the wall.

The crucible is mounted like an ordinary foundry ladle, and may be of cast iron, although wrought iron is preferable. Its proportions, as to depth and top and bottom diameters, seldom vary from those here shown. A small sheet-iron fan *d* is placed in the rear of the wall, and is connected to the tuyere-pipe by a loose leather pipe, having an iron ring at the end, which is slipped on and off the tuyere-pipe as required, being secured in place by a twist of iron wire.

The fan is generally driven by manual labour from a large wheel with winch handles, and an endless band. A high speed, 800 to 1000 revolutions per minute, is usual, as a strong blast is required.

The way in which this apparatus is set to work is as follows:—The crucible *c* is clay washed, and then lined with clay in the same manner as an ordinary foundry ladle, except that the clay lining is brought well up and over the tip all round, save at the one point where the tuyere-pipe opening is left. A fire of hard

coal is then kindled in the interior to dry the lining. The tower *b* is also lined in the same way and a roll of clay is formed round its lower edge, where it will have to rest upon the top of the crucible; this is dried by being placed over the fire in the crucible.

When the lining is thoroughly dry, the crucible, with the fire still in it, is placed in its proper position, so that the tuyere-pipe comes exactly opposite the vacant point left in the coating of clay round the tip of the crucible, with its two handles firmly resting upon the projecting fire bricks or lumps *e*, and its bottom supported upon a bed of well-rammed sand.

The tower is then placed upon the crucible, the edges of its open portion being in close contact with the wall; these edges are clay-luted to the wall face, and the lower edge of the tower is also luted to the upper edge of the crucible. Dry sand is next piled up round the outside of the apparatus, more fuel is thrown in at the top of the tower, and a gentle blast is kept on, until the fuel is in a bright glow, when charging commences, and is carried on in a similar way to charging a cupola.

The tuyere-pipe is so arranged that by a few simple wedges its angle can be materially changed; when first the blast is put on it is generally directed horizontally across the top of the crucible, but when the fuel is thoroughly ignited the blast is turned down more directly towards the bottom of the crucible; if the fuel employed be raw coal, and not coke, the blast is directed towards the centre of the bottom of the crucible.

When the metal is "down," the sand is moved away from around the *calebasse* down to the floor level, the luted joint between the tower and the crucible is broken, and the tower is lifted off by means of an iron bar passed through eyes on its top. The fuel falls out of the tower, and some has also to be raked away from the top of the fluid metal in the crucible, which is then skimmed with a wooden tool, and covered with powdered charcoal. The crucible is lifted from the hearth by its long iron handles, carried away to the moulding shop, and deposited on wooden bearers *f f*. The contents of the crucible can then be emptied into small hand-ladles, lined with clay in the usual manner.

In charging the furnace, pig and the heaviest scrap are put in first, and the lightest scrap last.

The amount of metal which can be brought down in one operation is entirely governed by the capacity of the crucible, and varies from a few pounds to half a ton.

Ordinary loam is found to be quite refractory enough for the lining, as it is only exposed to a great heat for a short time.

The apparatus shown is capable of producing 5 cwt. of metal at one operation, the time occupied being about an hour, when the metal should be white hot, and very liquid, if suitable pig and scrap have been employed.

The calebasse brings down the metal rapidly, and extremely hot and liquid, which is exactly what is required in the production of small fine castings. It is also stated that special qualities of iron can be obtained with more certainty from the calebasse than from a cupola. Another advantage is that three or four meltings per day can be obtained from the same apparatus.

Where fine castings are required, good coke, first-class pig, and best scrap iron only must be used; but, in many instances, where the quality of the metal is only of secondary importance, raw coal, as being cheaper than coke, and inferior scrap may be employed. The coal should be as free from sulphur as possible, hard, and not inclined to cake.

CHAPTER VI.

THE REVERBERATORY OR AIR FURNACE.

THE great advantage of this description of furnace is that it may be easily applied to a variety of different uses, with slight modifications in construction. The reverberatory and the crucible make the strongest, closest, and safest castings, whereas castings from a cupola are the weakest, except those which are obtained direct from the blast-furnace.

The reverberatory was at one time largely used for the fusion of cast iron for foundry purposes, although it has, to a great extent, been superseded by the cupola.

As an oxidizing furnace it is employed in the puddling of iron, and for producing litharge from lead. As a deoxidizing furnace it is employed in the production of lead and copper. It is also frequently used for calcining substances, which afterwards have to be pulverized, such as flints, &c.

Although the cupola has of late years almost entirely superseded reverberatory furnaces, there are several points in favour of the latter, which must not be lost sight of. The cupola is undoubtedly the cheaper and more generally convenient form of furnace, but where it is wished to turn out specially good work, and to obtain a perfectly fluid and uniform metal, the reverberatory furnace is preferable.

The deoxidating flame of the reverberatory is supposed to improve the pig iron, by adding somewhat to the amount of combined carbon it contains, whereas the cupola, as usually worked, with an excess of air, is an oxidizing furnace.

It is a generally admitted fact that, taking the same quality of iron, castings from the reverberatory are stronger than those from the cupola.

For the general character and quality of castings, it is to be regretted that the reverberatory furnace for the melting of iron is fast disappearing.

In two other respects the reverberatory presents advantages over the cupola; by it, in the first place, it is possible to melt a given quality of cast iron more absolutely free from change in its constituents, molecular or chemical; and, in the second place, if the pig iron contains a large proportion of sulphur, it can be freed from a great deal of this by prolonging the time the metal is exposed, after fusion, in the reverberatory, to a slightly oxidizing flame.

This latter action is seldom of any practical utility, for pig iron that contains much sulphur makes very indifferent castings, and the desulphuration is so imperfect and unreliable, that it is usually far cheaper and more certain in working to obtain a good pig iron at the outset.

The following are generally circumstances under which it may be considered advisable to use the reverberatory furnace in preference to the cupola:—

When there are no means for obtaining sufficient blast for a cupola:

When it is necessary to melt down such large masses of metal as cannot be managed in the cupola:

When it is required to bring a given pig iron, by deoxidation, to its highest point of tensile resistance, as for gun founding:

When it is necessary to erect a foundry under circumstances where a cupola with blast could not be built or worked; as, for example, in a lonely colony, a besieged town, or such other exceptional conditions.

Under most other circumstances the cupola is to be preferred, as the reverberatory is neither economical in metal nor fuel, except where the operations are constantly going on from day to day on a very large scale, and where good bituminous coal fuel is cheap.

The principal considerations governing the design of an air-furnace, are, 1, the weight and volume of metal required to be melted in one charge; 2, the quantity of fuel necessary for such a quantity of metal; and, 3, the regulation of the supply of air necessary for the proper combustion of that amount of fuel.

1. The proportion of the size of the bed of the furnace, and the cavity, or pool, for containing the melted metal, depends upon the weight of metal it is required to "bring down" in a charge.

2. The size and construction of grate are mainly determined by the quantity of metal in a charge, the quality of the fuel to be employed, and the speed at which it is desired to work.

3. The regulations for the supply of air require considerable attention. The supply must be amply sufficient in quantity to consume the required amount of fuel, and must flow through the fuel onwards to the chimney flue at a certain velocity, which velocity must be well within control, as upon it principally depends the "reverberatory" action of the furnace.

It is obvious that if the air entered the furnace in a slow, quiet current it would pursue the even tenor of its way, without coming into violent contact with either the roof or the bed of the furnace; this would greatly hinder the fusion of the metal.

Assuming, what is probably correct, that the hottest part of the current is the central stratum of the air and flame, the curve of the roof, and the position of the bridge at the back of the grate must be such that with a known velocity of air it will impinge against the roof in such a manner as to be directly deflected upon the metal on the bed of the furnace. If the velocity of the air be too great for the shape of the furnace it will probably be deflected earlier in its progress than is required.

Figs. 2 and 3, Plate XIV., are somewhat exaggerated diagrams of the evils to be expected either from too slow a current, as in Fig. 3, or from a too rapid current, as in Fig. 2.

From these sketches it will be seen that the proper direction of the heat depends very much upon the velocity of the current of the air through the furnace.

If too large a supply of air is admitted, either fuel will be wasted, or, what amounts to the same thing, the furnace and its contents will be cooled.

Cold air must be rigidly kept out of the furnace, and any cracks or fissures which might admit cold air must be carefully stopped up.

Flaming fuel, such as bituminous coal, is best adapted for the

air-furnace, except when gas is employed, as in the regenerative system.

Upon the nature of the fuel employed most of the success of the reverberatory furnace depends. A good gas flame driven through the furnace by a powerful blast. in the proper direction, and to the proper region of the furnace, will give excellent results.

Where solid fuel is employed, that which gives off plenty of combustible gas is preferable.

Wood is not a good fuel, but if it is to be employed the furnace must have a long flame-bed, and be low in the arch. Tolerably hard, long-flaming bituminous coal, which does not cake in the furnace, is the best kind of fuel.

Hard coal or coke may be used, but are not so good as bituminous coal. The disqualification arises partly from their incombustible nature, but chiefly on account of the mass of fine ashes which is carried over from the fireplace to the hearth, covering the melted iron and preventing its absorption of heat. This evil is more apparent in the use of anthracite than of coke. Wood, particularly green wood, is not at all qualified for use in the reverberatory; if no mineral coal can be obtained, charcoal is to be substituted for it.

Most other kinds of fuel are objectionable, as requiring constant attention on the part of the furnace man, either to feed the fire, to remove clinkers, or to break up the fuel, all operations requiring the furnace to be opened, and thus allowing the entrance of cold air, which is most objectionable.

To meet this difficulty, many plans of self-feeding hoppers, &c., have been advocated, but the difficulty still appears to be to properly regulate the fire, so as to consume the fuel with the best result in time and labour, without allowing the ingress of cold air, whilst such arrangements are being made, bearing in mind the fact that the operations inside the furnace require continual supervision, as they are continually varying in their nature and effects.

It is important that the furnace should be connected with a chimney which will give a powerful draught, to which end it should be lofty, and about equal in area to the grate surface of the furnaces it draws from.

The arrangement of the grate and fire-bars is governed to a great extent by the nature of the fuel to be employed. Assuming that 25 lbs. of coal will be burnt per hour for every square foot of grate surface, ample space must be left between the fire-bars to allow of the passage of sufficient air to support such a combustion, namely, about 230 cubic feet of air for each pound of coal burnt in the furnace.

Turf and peat are occasionally useful for heating drying stoves, drying ladles, &c., or for the production of steam power, but for most other purposes they are almost worthless.

Turf gas has been employed in Germany for reverberatories, but where gas from any better fuel is at all obtainable this will never be used.

Pit coal is not only the best *solid* fuel to be used in the reverberatory, but also gives off the best gases, should it be intended to heat the reverberatory with gas from a gas-producer. In the latter case, when the furnace becomes a magnified gas blowpipe, it is necessary that the air and gas fed into the furnace should be at a high temperature. Hence the importance of the Siemens regenerative furnaces, which provide the necessary heat for gas and air; or the air alone may be heated before admission into the combustion chamber, by being passed through heating stoves, or pipes.

In the construction of these furnaces the most refractory materials should be employed, and in all parts which are exposed to great heat care should be taken to select fire-bricks and clay whose constituents are such as not to have an injurious chemical action upon the metal to be melted. The great strains brought upon a furnace which is worked at such a high temperature necessitate care in the selection of materials employed, and skill in design and construction. If the furnace should fail, it will probably do so at the time when it is at its greatest heat, with a quantity of molten metal and burning fuel, which would be scattered around, killing the workmen and probably destroying the foundry.

The furnace should therefore be cased with strong iron plates and tie-rods, and this casing covering over all the brickwork of the furnace, all ingress for cold air is stopped.

The construction of an air-furnace suitable for the fusion of

cast iron, copper, bronze, or brass, is shown in Fig. 1, Plate XV. *a* is the hearth, *b* the bridge, *c* the sole-plate or bed of the furnace, all covered over by the reverberatory arch, which is usually curved over both from the side walls and the ends; *d* is the flue to chimney, *e* the tapping hole, through which the fluid metal is run away, at other times being stopped up with a fire-clay plug; *f* is the entrance for heated air, which passes through the fuel, carrying the flames and products of combustion upwards, where they impinge upon the crown of the furnace, which deflects them downwards upon the metal lying on the sole, at which point it is desired to obtain the maximum heat of the furnace.

This current flows in the direction shown by the arrows and dotted lines. Charging doors must be arranged for the supply of metal and fuel; small sight-holes, which shall allow an examination of the work in progress, without permitting much cold air to enter the furnace; and dampers, to regulate the draught, so placed as to escape the greater heats of the furnace.

Several modifications of this construction are employed. The air-entrance *f* is frequently placed immediately under the hearth; or the sole *c* is made to slope downwards towards the bridge *b*, with the tapping hole *e* almost immediately behind the bridge; or the sole may be made flat, so that it will be filled to a uniform depth with the liquid metal.

The construction of furnace here shown is intended for the use of heated air, which is introduced at *r*, should it be desired to economize the waste heat passing from a cupola, the flame and heat from which would unite with those from the fire in the air-furnace itself. Where the air necessary to support combustion will be directly supplied from the atmosphere, it must be passed in through the fuel so as not to come in direct contact with the roof of the furnace, or of the metal to be melted.

The principle of the reverberatory furnace is so to deflect, or direct, the currents of flame and heated air that they may exert their most intense power upon the metal lying on the bed of the furnace, in which respect the air-furnace somewhat resembles the action of the blowpipe, with which the greatest concentration of heat on a certain body can be effected in the least time.

The fire-bars should be of good wrought iron, although hard

white cast-iron bars are frequently used. The area of the vertical cross-section of the furnace over the bridge must be considerably less than the area of the air-passage in the grate.

The hearth slopes gradually towards the chimney, and forms a basin for the accumulation of the melted metal. The fire-bridge, which separates the fireplace from the hearth, is from 10 to 15 inches high, according to the capacity of the furnace. One side of the furnace is provided with a large iron sliding door for charging iron and repairing the hearth; this door is at the highest part of the hearth, near the fire-bridge. In the lowest part of the hearth, in the centre of the basin, is the tap-hole. This may be at one side of the furnace, or behind the stack at the flue. A damper on the top of the stack is useful to regulate the draught. The furnace should be very thick in the walls, so as to be as bad a conductor of heat as possible. Too much attention cannot be paid to the joints in the brickwork; any openings which might admit air are to be carefully stopped up, or the iron is liable to a loss of carbon, and will make, in consequence, hard and brittle castings.

The pig iron is here charged behind the fire-bridge, and as it melts, flows down into the basin. Such impurities as adhere to the pig iron which will not melt remain at the top of the bridge, and may be removed after the heat. Thus the melted iron is purified to a large extent. The heat of the furnace is generally greatest near the flue, and the melted metal is therefore exposed to the strongest heat of the furnace.

When a cast is to be made at a certain time, the reverberatory is heated for some hours previously by a brisk fire. When the furnace is white hot the charging door is opened, and the pig iron is placed in its proper position on the sole, due care being taken in stacking the metal as will be described, the most easily fusible portions being first charged and put at the bottom of the heap. The whole quantity of iron which it is desired to melt at one heat must be charged at the same time, as it is not considered advisable to add cold iron to that which is already melted. All the iron contained in a liquid form in the basin is to be tapped before any fresh pig can be charged. When all the iron contained in the

furnace is melted, the tap-hole is opened with a sharp crowbar, and the liquid iron is either led into pots or directly into the mould. The tap-hole is stopped with damp sand, or a mixture of loam and coal-dust. When the furnace is charged with iron, all the openings and joints at the door and in the brickwork are to be cautiously stopped with moist loam, to prevent the access of any air upon the hearth. The fire-grate must also be well attended to, and kept well filled with coal, but not too high, so as to impair the draught of air through the fuel. The grate should be kept free from clinkers, and the formation of holes where unburnt air could enter the furnace must be prevented.

The charging door is generally a fire-block hung in an iron frame, which is raised and lowered by a lever, having a balance weight. All joints through which any cold air could enter the furnace must be covered with fire-clay or loam. The metal to be melted should be broken to an uniform size as far as possible, and on placing it in the furnace, the smallest pieces should be piled lowest, the larger ones on the top, as the heat of the flame is there more intense, which is what is required for the larger lumps of metal, and a similar plan must be adopted with regard to the melting of various qualities of metal, the most easily fusible being placed lowest in the furnace. Fuel should be fed in frequently, and it must be done quickly.

When sufficient molten metal has accumulated in the pool of the furnace, it is tapped off. The chimney damper is first closed, the metal is then run into a ladle or is run along plate-iron shoots covered with loam, to the mould, being skimmed by the dam-plate, and by men, as it flows along, or into a pool in front of the furnace, the slag being removed before the metal passes into the moulds.

The furnace is then cleared out, and any necessary repairs executed before it is again charged. If the repairs have been considerable, it will be necessary to make the furnace white hot before again charging it for use.

The reverberatory furnace is not only used for melting iron, but is also employed for the melting of large quantities of brass, bronze, tin, lead, and other alloys and metals. Large bells, statues, machine frames, and similar objects, are cast from the reverberatory furnace.

All metals, except very grey fusible iron, which may be cast from a pot, are to be run in dry sand ditches, directly from the furnace into the mould.

Fig. 2, Plate XV., shows a section of an air-furnace in which the roof is so constructed as to deflect the heat on the bed of the furnace in two places; by which arrangement a larger area of metal is acted upon, and heat is economized.

In cases of furnaces for melting bronze, it is sometimes necessary to build them with large charging doors, to permit of the introduction of heavy masses of metal.

Figs. 3 and 4, Plate XV., show a brass furnace thus arranged, which construction could, however, be adopted for the fusion of cast iron. There is a large charging door at the end near the chimney; the lower door is for tapping.

Furnaces for melting bronze should have a rather shorter flame-bed than is used for melting cast iron.

Bessemer's patents contain several suggestions which seem admirably adapted for forming a fresh point of departure for scientific furnace building. The original 1868 specification is most comprehensive in its claims, but the main features may be indicated as: the construction of furnaces for fusing difficultly fusible varieties of iron and steel, with a shell of riveted boiler plate or cast iron, lined with plumbago, fire-brick, or gannister, in which, by supplying air through tuyeres at a very high pressure, from 2 to 6 lbs. in excess of that it is intended to maintain in the furnace, while the products of combustion can only escape through contracted openings, of which the area can be reduced or enlarged at will by the insertion of stoppers, the combustion products are kept from expanding freely. The pressure to be maintained in the furnace is always to be at least 1 lb. in excess of that of the atmosphere, and may range to several atmospheres. The combustion in furnaces of liquid hydrocarbons, and gaseous, as well as solid, fuel, under high pressure, with details of the construction proper for each modification, and minute details for the construction of cupola, reverberatory, and other descriptions of furnaces, suitable for the application of "high-pressure" combustion, are some of the points embraced in the specification. The design of feeding-doors, so arranged that the fuel and metal may be introduced without permitting the escape

of the heated gases, and the application of water-cooling to the escape orifice, are instances of practical difficulties ingeniously overcome. In subsequent patents it is proposed to employ cupola and reverberatory furnaces but slightly differing from the ordinary construction, but enclosed in strong iron chambers. This external or working chamber is supplied with air at a great pressure, and the furnace draws its supply of air from the reservoir; the pressure is maintained in the combustion space by contracting the furnace mouth.

Another proposed application of the high-pressure system is to the Bessemer converter. Bessemer has, of course, especial claims to be heard when he proposes any modification of the process with which his name is identified, but the advantages of this application are perhaps hardly so considerable as he estimates them to be. It is well known that certain varieties of hematite and Swedish pig are, from a deficiency in carbon or silicon, the cause of great trouble in the converter, owing to their not blowing hot enough, with the result of leaving "skulls" of solidified steel in the converter, a highly objectionable result, as need hardly be said. In order to increase the heat of the blow in these cases, and to enable steel and other scrap to be melted down in the converter, and also to facilitate the decarburation of iron by means of nitrates—a process in which it is difficult to maintain the melted metal at a sufficiently high temperature—the inventor of the pneumatic process now proposes to conduct the whole operation under pressure. To effect this he either makes the mouth of the converter of very contracted dimensions, or provides it with a movable conical stopper by which the dimensions of the orifice may be regulated at pleasure. The body of the converter is made of extra strength, and the blast supplied at a pressure very considerably in excess of that ordinarily used in the process, so that the gases may be retained at a pressure considerably in excess of that of the atmosphere. By this means he expects to raise the temperature of the metal in the converter to a very great degree.

In order to illustrate the mode in which it is proposed to carry these ideas into effect, sections of the furnaces are given in Figs. 1 and 2, Plate XVI., and Fig. 1, Plate XVII. Figs. 1 and 2, Plate XVI., are longitudinal and cross vertical sections of a form of

reverberatory furnace. To facilitate relining, the central portion *a* may be removed from the rest on a truck, and when the repairs are completed it is replaced, and fixed in position by bolting together the flanges *d*, *e*, *g*, *h*. The cover of the charging hole *x* is kept in position by air or steam pressure on a piston, working on the cylinder *t*, actuating the lever *y*.

The metal is charged into the furnace through strong circular side doors *m*.

Fig. 1, Plate XVII., represents a high-pressure crucible furnace built of riveted plates, with a refractory lining. Four openings J, in the dome, allow of the introduction of twelve crucibles and the required fuel-charge. These openings are closed by an iron plate L, fitting into a conical seat N, on which it can be screwed down by the bar and screw P and O. The fire-clay stopper K serves to protect the iron cover from the intense heat of the furnace. The combustion products escape at the contracted orifice Q, and the blast is admitted through tuyeres T.

It is somewhat remarkable that no attempt has been made on the large scale to put the idea of high-pressure furnaces to a practical test, especially as the prestige of their inventor might naturally be expected to predispose practical men in their favour. Experience alone can prove if the economical advantages to be derived from intensity of temperature in certain metallurgical operations will outweigh the additional cost of the plant and blast power by which this intensity of temperature is sought to be obtained on the high-pressure system. It is stated, however, that in a very small furnace burning coke, with an average internal pressure of 15 to 16 lbs. over that of the atmosphere, 3 cwt. of wrought iron (engineer's scrap) put in cold, was fused into a liquid bath in less than fifteen minutes. As a somewhat comparable result may be instanced the fact that it takes twelve minutes immersion in the bath of pig, after ten minutes' exposure on the bank in a Siemens furnace, to melt a somewhat larger quantity of 8-inch cubes of wrought iron. How sensibly immersion in melted cast iron accelerates the fusion of wrought iron is well known. In another instance a 12-inch length of 2-inch square bar iron was reduced to perfect fluidity in five minutes.

CHAPTER VII.

MEASURES OF HEAT, THERMOMETERS AND PYROMETERS.

In nearly all the processes connected with metals and their alloys, constant reference is made to the temperatures at which certain operations have to be performed. The instruments used for observing these temperatures are known as the thermometer, or measure of heat; and the pyrometer, or measure of fire.

The first is employed for all temperatures up to that at which mercury boils; the second is more particularly used to ascertain those higher temperatures in which the nature and construction of a thermometer will not allow of its use. The thermometer deals with a range of heat comparatively easy to register and observe, and reliable instruments may now be obtained, regulated to an extreme degree of precision. Although much ingenuity has been employed in the construction of pyrometers, great doubt is felt with regard to their accuracy, more particularly at very high temperatures. There is yet room for improvement in this respect, as a delicate and reliable instrument for the observation of high temperatures would be of great service to scientific men and manufacturers.

The latest invention, that of Siemens' electrical resistance pyrometer, bids fair to be of great utility, but as it is somewhat expensive, and of a rather complicated construction, it is not likely to be very rapidly adopted for ordinary workshop use.

Of all bodies, liquids are preferable for the construction of thermometers, as solids are not sufficiently dilatable, and gases are too much so. Mercury and alcohol are exclusively employed in their manufacture; the first, because it does not boil but at a very high temperature, 600° Fahr., and the second because it does not solidify at the coldest point known. Mercury is generally used. The instrument is composed of a capillary glass tube, terminating in a cylindrical or spherical bulb of the same material. The reservoir and a part of the stem are filled with mercury, and

by a scale, graduated on the tube itself, or parallel to it, we ascertain the expansion of the liquid. On the stem, two fixed points are marked, representing always identical and easily reproducible temperatures. Now, experience has shown that the temperature of melting ice is invariably the same, whatever may be the source of heat, and that distilled water constantly boils at a particular temperature, provided there be the same pressure, and a vessel of the same material. Consequently, for the first point, the temperature of melting ice has been taken, and for the second the temperature of boiling distilled water. These two having been defined, the intervening space is divided into equal parts or degrees, and these divisions are continued the length of the scale.

In the graduation of thermometers there are *three scales*, the Centigrade, invented by Celsius, Réaumur's, and Fahrenheit's; the first is used in France, and by authors of scientific works in other parts of Europe, England excepted. Réaumur constructed his thermometer in 1731, adopting the same freezing and boiling points as Celsius; in the Réaumur the intervening space is divided into 80 degrees, so that 80 degrees Réaumur are equivalent to 100 degrees Centigrade: 1° R. is therefore equal to $\frac{100}{80}$ or $\frac{5}{4}$° of Celsius, and, reciprocally, 1° C. is equal to $\frac{80}{100}$ or $\frac{4}{5}$° R. Consequently, for converting a number of degrees R. into degrees C.—20 for instance—this number must be multiplied by $\frac{5}{4}$, because 1° R. is equal to $\frac{5}{4}$° C. 20° R. converted into C. are 20 times $\frac{5}{4}$, or 25. It is obvious, also, that for converting the degrees of C. into those of R. they must be multiplied by $\frac{4}{5}$.

Fahrenheit, in 1714, invented a thermometrical scale, which is popular in Holland, England, and the United States. The upper fixed point of this instrument corresponds with the boiling point of water; but a temperature obtained by mixing equal parts of pulverized sal-ammoniac and snow together, is marked 32°, the intervening space being divided into 180 degrees.

Thus the thermometer of Fahrenheit when placed in melting ice, stands at 32°; consequently 100° Centigrade are equivalent to 212 minus 32 or 180; 1° C. is therefore equal to $\frac{180}{100}$ or $\frac{9}{5}$° F.; and, reciprocally, 1° F. is equal to $\frac{100}{180}$ or $\frac{5}{9}$° C.

Suppose a certain number of degrees Fahrenheit, say 85, have

to be converted into degrees C. For this purpose, first, 32 must be subtracted from the given number, so as to count the two kinds of degrees from the same point of the stem. The remainder is 53. And, as 1° F. is equal to $\frac{5}{9}$° C., 53° are equal to $\frac{5}{9} \times 53 = 29\frac{4}{9}$ C. Reciprocally, for converting degrees of C. into degrees of F., the given number must be multiplied by $\frac{9}{5}$, and 32 added to the product.

To make a thermometer. Take a fine glass tube blown into a bulb at one end. Heat the bulb; the air then expands; place the tube under mercury, which will enter the tube as it cools. It must then be so managed that the mercury stands at convenient height in the tube at ordinary temperatures.

Apply heat until the mercury expands to the top of the tube, seal the tube by heating it, and pinching the glass together with a pair of nippers. If this is neatly done, the mercury on cooling will sink in the tube, leaving a vacuum above it. The boiling point of distilled water is 212° Fahr., at the ordinary barometric pressure, and the freezing point of water is 32° Fahr., consequently the boiling point and the freezing point are easily obtained. The intermediate space is divided into 180°. In both the Centigrade and Réaumur thermometers the freezing point is marked *zero* (0), the boiling point in the Centigrade is 100°, whilst in the Réaumur it is 80°.

Spirit thermometers are used for taking very low temperatures, as spirits cannot be frozen.

Registering thermometers are made by contracting the neck of the bulb, so that when the mercury expands upwards by heat, a portion of the mercury will remain to indicate the highest point reached. Another mode is to separate a small portion of the mercury by a small air-bubble, from the rest. To reset the thermometer, allow it to cool, and then shake down the small portion of mercury which registers the high temperature.

In measuring the melting points of metals, the temperature must be taken just before melting takes place, because at the moment of liquefaction a certain quantity of latent heat is absorbed, and beyond that point the temperature of the melted metal might rise considerably, and make the observation incorrect; as a thermometer cannot then be directly applied a pyrometer is employed.

Numerous pyrometers have been devised for ascertaining temperatures by the expansion of air from heat. This is the principle of the pyrometers ot Schmidt, Petersen, and Pouillet. Where these instruments can be conveniently applied, they are capable of yielding very accurate results.

The final indications of this kind of pyrometer will of course be arrived at by the laws of expansion of air and gases by heat. M. Regnault gives the amount of expansion of atmospheric air heated from 32° Fahr. to 212° Fahr. as ·3665 or ·3670 on its original bulk at 32° Fahr.

Wedgwood's pyrometer was founded on the property which clay possesses of contracting at high temperatures. The apparatus consisted of a metallic groove, 24 inches long, the sides of which converged, being half an inch wide above, and three-tenths of an inch below. The clay was made up into little cylinders, or truncated cones, which fitted the top opening of the groove when they had been heated to redness; and their subsequent contraction, when still further heated, was shown by their sliding gradually down the groove till they arrived at a part of it through which they could not pass.

This measure of heat is no longer employed by scientific men, as its indications cannot be relied upon, owing to the variations in the quality of clay, &c.; but there are times when the principle involved in its construction may be of use for rough approximations of high temperature.

Wedgwood divided the whole length of the groove into 240°, each of which he supposed equal to 130° Fahr., and he fixed the zero of his scale at the 1077th degree of Fahrenheit's thermometer.

He assumed that the amount of contraction of the clay would be always proportionate to the degree of heat to which it might have been exposed. This is erroneous, for it is found in practice that a long-continued and moderate heat will cause the clay to contract to an equal amount as a fiercer heat applied for a short period.

Another proof of its inaccuracy is to be found in the absolutely impossible temperatures recorded in some chemical books as being obtained by this instrument. Thus it has been stated that cast iron melts at 17,977° Fahr., and that iron welds at 21,000° Fahr.,

whereas it can be shown that the utmost temperature to be obtained by the combustion of carbon with atmospheric blast cannot exceed 4600° Fahr., a temperature far exceeding even the melting point of mild steel.

Since the invention of the above in 1782, a number of other heat measurers have been constructed, of which the following are the most useful and reliable:—Daniell's, Schmidt's, Gauntlett's, Wilson's, Bailey's, Carsatelli's and Siemens's Electrical Pyrometer.

The great majority of substances expand, when heated, more particularly the metals, and steel expands, when heated, more when tempered than when not tempered.

In Professor Daniell's pyrometer, the temperature is measured by the expansion of a metal rod, enclosed in a case composed of black-lead and clay, in fact of the same composition as a plumbago crucible, in which is drilled a hole $\frac{3}{10}$ of an inch in diameter, and 7½ inches deep. Into this hole the cylindrical rod of soft iron or platinum of nearly the same diameter, and 6½ inches long, is introduced so as to rest against the solid end of the hole; and upon the outer or free end of the metallic rod rests a cylindrical piece of porcelain, called the index. When the instrument is heated, the metal, expanding more than the case, presses the index forward, which, by means of a wedge, is kept in the position to which it has been forced, when the instrument is removed from the furnace and cooled. A scale is then attached to measure the precise extent to which the index has been pushed forward by the metallic rod; it thus indicates the difference between the elongation of the platinum rod, and that of the black-lead case which contains it. For its indications to be absolutely correct, it is necessary that the rod and the case should expand uniformly, or both vary at the same rate.

A very inconvenient circumstance attending the employment of this instrument is that no indications of temperature can be obtained by it until it is removed from the furnace.

Gauntlett's pyrometer is constructed on the principle of observations made upon the differential expansion of rods, or tubes, of brass and iron. This cannot be relied upon beyond a point approaching red heat, at which permanent elongation of the metals sets in. Such pyrometers are within limits, however, very useful,

and several varieties are made, of which two are illustrated in Plates XVIII. and XIX., the former showing Carsatelli's and the latter Bailey's.

The instrument made by Carsatelli consists of a tube *a* of iron or other metal, which at one end is screwed into a metal cone *b*, having through it a number of transverse holes *c*, and at the other end to a flanged socket *d*, and inside the tube *a* there is a second or smaller tube *e* of metal, the ratio of expansion of which by heat is different from the outer tube. This inner tube *e* is also screwed at one end to the metal cone *b*, and has at the other end transverse holes *f*, and a plug *g*, into which is screwed one end of a rod *h*, which passes through a stem *i*, screwed and adjusted to the flanged socket on the top of the outer tube, and afterwards held firm by the nut *k*; and to this stem *i* is fixed a case provided with a dial. The other end of the rod *h* is in contact with a small block *n* pivoted to an arm *o* of the toothed quadrant or segment *p* gearing into a pinion on the spindle carrying the index hand, and as the rod *h* is moved up or down, according to the expansion or contraction of the tubes of metal, it gives motion to the toothed quadrant and pinion, and consequently to the index hand. The hot blast is passed through the instrument by inserting the cone *b* into the socket of the plug of the tuyere-tube, or other suitable place, the current passing through the inner tube through the holes at the top, between the inner and outer tubes, and out through the holes *c* in the cone.

The outer tube A has a cover T of wood, or other non-conducting material, encircled by felt or cloth *u* for preventing the radiation of heat from the instrument, and enabling it to be handled comfortably.

In W. H. Bailey's pyrometer, Plate XIX., an attempt is made to preserve a portion of the length of the rods employed non-pyrometrical, in order that when it becomes necessary to pass the stem of the pyrometer through brickwork, as in the case of a furnace, that portion of the stem which is actually in the heat shall alone be utilized for pyrometrical purposes; thus a more accurate indication of the heat is obtained, and the permanent expansion of the materials reduced to a minimum.

Arrangements are made to return the index finger to zero when

required, and there are also two hands, one of which makes a complete revolution for every degree indicated by the other, and thus at every revolution of the smaller hand the larger hand will only move one degree, but in its whole revolution will indicate the total heat.

In Fig. 1, Plate XIX., A is a wrought-iron tube, passing through the brickwork B, and having a brass or copper tube C, screwed in on the other side of the brickwork as illustrated. D is a wrought-iron rod connected with a quadrant at one end for actuating the index spindle, and which rod, being of the same material as the tube A, only that portion of its length which extends beyond the mouth of such tube A into the furnace or oven has any influence in indicating the temperature of the furnace or oven by the difference in its expansion as compared with the brass or copper tube C, but any other materials which expand unequally may be employed either in the form of rods or tubes, provided that the tube which passes through the brickwork is compensated for by an inner tube or rod of the same material and length as the tube or casing A.

In Figs. 2 and 3, E is the index spindle carrying the index hand F, disc wheel G, and mill-headed knob H, all firmly secured upon the spindle. I is a toothed pinion combined with a ratchet-wheel J, which is mounted loosely upon the spindle E, but is compelled to turn with it in one direction by the application of a spring pawl K, mounted upon the face of the disc wheel G, and taking into the teeth of the ratchet-wheel J; the pinion I gears with the ordinary toothed quadrant L, which is connected with the internal tube or rod, upon the expansion of which, as compared with the external tube, the indicating depends. This pinion acts upon the spindle E, as if it was fixed thereupon, but if, through permanent expansion of either of the differently expanding materials employed, the index finger F fails to return to the starting point, by turning the nob or handle H, the spindle may be turned in the direction of the arrow without affecting the position of the pinion, as the spring pawl K permits the disc wheel G to turn independently in that direction, and thus the instrument may be adjusted to the greatest nicety. To ascertain the fractions of a degree of temperature, a toothed wheel M is fitted to the spindle E gearing

with a pinion N, which turns a pointed hand O indicating upon a smaller dial.

The principle of the measurement of high temperatures founded upon the quantity of heat imparted to a given bulk of water, at some known temperature, by plunging therein a heated body, is that upon which Wilson's pyrometer, Figs. 1 and 2, Plate XVII*a.*, is based.

The instrument consists of a copper vessel A, capable of holding rather more than a pint of water, and well protected against radiation by having two double casings around it, the inner containing air, and the outer filled with felt. A good mercury thermometer B is fixed in it, having in addition to the ordinary scale a small sliding scale C, graduated and figured with 50° to 1° of the thermometer scale: there is also provided a cylindrical piece of copper D, accurately adjusted in size so that its total capacity for heat shall be $\frac{1}{50}$th that of a pint of water. In using the pyrometer, a pint of water is measured into the copper vessel, and the sliding pyrometer scale C is set with its zero at the temperature of the water, as indicated by the mercury thermometer B; the piece of copper is then attached to a piece of wire placed in the substance, the temperature of which it is wished to ascertain, and is allowed to become heated for about two minutes, when it is quickly dropped into the water in the copper vessel, and raises the temperature of the water in the proportion of 1° for each 50° of temperature in the copper; the rise in temperature may be read off at once on the pyrometer scale, and if to this is added the actual temperature of the water, as shown on the scale of the mercury thermometer, the exact temperature is obtained. This pyrometer is found to be more accurate than others for such temperatures as will not melt platinum; for still higher temperatures a piece of platinum would be used instead of copper, and the instrument would then be available up to the highest temperature that platinum would stand. Of course this instrument cannot be used for taking observations in inaccessible places.

Another mode of utilizing a thermometer in measuring high temperatures approximately is Main's pyrometer, shown in Fig. 2, Plate XVII. Here D represents a hot-blast pipe, and A the apparatus, which consists of three concentric cylindrical vessels of copper or brass. In the inner chamber a delicate thermometer is

placed, and the hot blast, conducted by the tube C from the pipe D, circulates through the second chamber, passing out by the tapered nozzle E. The outer space is filled with a substance of low conducting power.

The temperature indicated by the thermometer does not, of course, represent the actual temperature of the hot blast; but to ascertain this it is only necessary to insert a metallic pyrometer in the hot-blast pipe D, and compare the relative indications, in order to fix a ratio. Any ratio desired may be obtained by a simple adjustment of the bore of the tapered nozzle. When the object is only to regulate the temperature of the blast this adjustment is not required, it being sufficient to note the degrees indicated by the thermometer when the blast is at the ordinary working temperature, and thereafter maintain it at that point.

The electrical resistance of metal conductors depends upon their dimensions, material, and upon their temperature; an increase of the latter causing a corresponding increase of resistance. The law of this increase is known. Thus the resistance of a conductor being ascertained at 0° Centigrade, it can be calculated for any temperature, and, *vice versâ*, if the resistance can be found by measurement, the temperature can be calculated. And this is the principle upon which Siemens' electrical pyrometer, Plate XX., is based.

A platinum coil of a known resistance at 0° Centigrade is coiled on a cylinder of fire-clay, protected by a platinum shield P, which is placed in an iron or platinum tube, and then exposed to the temperature to be determined. Leading wires *l l* are arranged to connect this coil with an instrument suitable for measuring its resistance, and from this resistance the temperature can be calculated. These leading wires can be brought from the furnace into an office, where the temperatures could be read off, and recorded as often as required.

The resistance measuring instrument supplied for the purpose is a differential voltameter. This consists of two separate glass tubes, in each of which a mixture of sulphuric acid and water is decomposed by an electrical current passing between two platinum electrodes. The gas which is generated is collected in the long cylindrical and carefully-calibred top of the tube, and its quantity is read off by means of a graduated scale fixed behind the tubes.

Movable reservoirs are provided communicating with the tubes to regulate the level of the liquid.

The current of the battery is divided by passing a commutator into two circuits, one of which consists of an artificial resistance in the instrument and the platinum electrodes in one tube; the other, of the resistance to be measured and the electrodes in the other tube. The quantities of gas developed in the two tubes are in inverse proportion to the resistances of their respective circuits, therefore one of the resistances, viz. that in the instrument, being known, the other can be calculated.

The makers give the following directions for use:—Fill the battery glasses with pure water, or, in case of the power of the battery decreasing, with a solution of sal-ammoniac in water. Connect the poles to B and B on the commutator. Expose the small end of the pyrometer tube, as far as the cone, to the heat to be measured, and connect the terminals X, X′, C to the ends of the leading cable, bearing corresponding letters. Connect the other end of the leading cable to the terminals X, X′, C on the voltameter.

The differential voltameter is to be filled with the diluted sulphuric acid through the reservoirs, the indiarubber cushions being lifted from the top of the tubes. The commutator is to be turned so that the contact springs on both sides rest on the ebonite. The liquid in both tubes is to be regulated to the same level, 0° of scale, and the indiarubber cushions to be let down again. Give the commutator a quarter of a turn, and the development of gas will commence almost immediately. Turn the commutator half round every ten seconds to reverse the current. Keep the current passing until the liquid has fallen in the tubes to at least 50° of the scale, then put the commutator in its first position, so that the contact springs rest on the ebonite; read off the level of the liquids on the scale marked V, and the scale marked V′; find these numbers in the table under V and V′, and the intersecting point of the lines starting from these figures gives the resistance of the exposed coil in black, and its temperature in red, figures. These pyrometers are made by Messrs. Siemens Brothers, Woolwich.

CHAPTER VIII.

REFRACTORY MATERIALS.

ALTHOUGH the success of metallurgical operations depends so largely on the possibility of finding proper refractory materials, and they enter so prominently into the cost of these operations, it can hardly be said that our knowledge of them is in a very satisfactory condition, or even that we know very much about them, beyond a few facts which have been gathered through their use. Experience, as a general thing, is an excellent master, but the requirements of modern metallurgy increase so rapidly that the acquirements of experience become as rapidly useless, because the exactions of temperature increase so fast, that the material depended on yesterday is of but little value to-day. No materials are required to resist so many and such varied conditions as those required for crucibles, retorts, and furnace linings.

Such is the opinion expressed by Dr. T. Egleston in a valuable paper on refractory materials, read before the American Institute of Mining Engineers, and to which we are indebted for the major part of the present chapter.

Dr. Egleston goes on to observe, that in the use of a given refractory material it will often be found that the same substance is called upon to fulfil conditions which are not only different, but exactly the reverse the one of the other. At one time it must resist an oxidizing, and immediately after withstand more or less of a reducing action. Now the action must be neutral, followed by the corrosive action of scorias, or sulphuric acid, or it must withstand the action of basic scoria, and immediately afterward only resist the action of metals in fusion. The same substance must resist the destructive action of melting as well as melted oxides, sulphides and silicates, and at the same time be proof against any amount of heat. We seem to be astonished, and often complain, that one brick which

resists the influence of oxide of iron, should fail entirely under a gas flame, and that another should slag under the influence of oxide of iron, but resist clear heat well, and yet, when the nature of the material is considered, we see that it could not very well be otherwise. In many cases, and in certain portions of a furnace, the brick may be called upon only to support a very high temperature, coming in contact with the flame alone, and this is the most trying condition of all our modern requirements, for under these conditions the material must resist the temperature, and remain infusible without decomposition, cracking, or alteration of any kind, and still retain strength sufficient to resist the pressure of the furnace.

The substances with which we have to deal as refractory materials are silica, alumina, lime, magnesia; clays which are silicates of alumina, more or less pure; the hydrated aluminate of iron, known as bauxite, and some silicates of magnesia, as talc, steatite, and the minerals which are allied to them, all of which substances are fusible in the strict sense of the word, but are generally infusible at commercial temperatures. To these substances two others must be added as powerful agents to render infusible, under certain conditions, substances which would otherwise be fusible, and these are water and carbon, in the shape of coke or graphite.

Some few rocks are used as refractory materials, without undergoing change. These rocks are quartzites, granites, some sandstones, conglomerates, serpentines, steatites, and, in certain cases, as in Styria, carbonate of lime. Quartzite and sandstones were, for a long time, used almost exclusively for blast-furnace hearths. They are very refractory, but very treacherous, as they are not homogeneous. Some aluminous shales are also used, and will, generally, resist, if they do not contain more than from 4 to 6 per cent. of iron, the alkalies and the alkaline earths together, but it is not easy to use them. They are not easily cut, must be laid in their quarry bed, and are liable to crack. Other rocks of the soapstone and serpentine varieties, which contain 60 to 65 per cent. silica, and 20 to 25 per cent. magnesia, are infusible, easily cut, and, if they do not crack, can be used; but, in general, natural substances are not homogeneous, are difficult to get in sufficient quantities, and so little to be depended upon, that artificial materials are preferred.

Silica is found in nature as anhydrous and hydrous. The

anhydrous, which is quartz and jasper, cannot be used alone, as it cracks and splinters. If it is to be used, therefore, it must be reduced to powder. The hydrous varieties gelatinize with acids, and are found as powders and soft stones, which pass under different names in different countries. They contain from 30 to 87 per cent. gelatinizing silica, from 2 to 10 per cent. water, and from 0 to 40 per cent. insoluble silica, with from 2 to 10 per cent. of iron, alkalies and alkaline earths. These impurities are generally in too small quantities to affect their refractory qualities. The rock is so tender, that M. Deville has had crucibles made in a lathe out of it, but, as the composition is never regular, vessels made by mixture are always better. Though silica is infusible, it cannot generally be used without being ground, and, as it has no binding quality like alumina, a small portion of binding material must be added to make it hold together. For the Dinas brick, which is the best substance to resist heat alone, this binding material is lime. The brick is made of quartzose sandstone, which is first heated in a furnace, and thrown into water, to break it up, and is then ground. It is composed of

SiO^2	98·31 to 96·78	Fe^2O^3	·18 to ·48	UaKO	·14 to ·20
Al^2O^3	·72 to 1·39	CaO	·22 to ·14	HO	·35 to ·50

The amount of lime required to bind it together is 1½ per cent. The joints between the bricks are filled with the same material. At a temperature of 2200° C., about 4280° Fahr., these bricks will last four weeks in the roof of an ordinary furnace, and in that time will be reduced, by abrasion of the flame, and dust, and slightly from chipping, from 9 to 2 inches. The bricks conduct the heat so badly, that at this temperature, which is a bright white heat on the inside o. the furnace, it is only just warm on the outside. Ordinarily, the bricks seem to be fluxed away by the dust, which circulates with the gases. In the Siemens furnace, where there is no dust, they give out from weakness. They cannot be applied to any part of the furnace where there is any wear. Their principal cause of deterioration seems to be, the lowering of temperature due to stoppages on Sunday, when the bricks flake, either as the furnace cools, or when it is again heated. It was at first supposed that these bricks could only be made from the Dinas stone, but it is now

known that they may be made from any pure silicious rock which has been ground and mixed with the proper quantity of lime.

In ganister, used for the Bessemer converters, the binding material is alumina, chemically combined with silica, in the shape of clay. It is generally unburned, and it is very important that the mixture should be so made, that it will expand a little, but not shrink at all. For this purpose, quartz, as pure as it can be had, is mixed with aluminous clay.

Silica is generally a very cheap material, and preferable to any other substance if it is used only to resist heat, but cannot be used if any considerable quantity of scorias are formed. In such cases bauxite, or other aluminous material, will be found to be preferable.

Lime, or lime rocks, cannot be generally used in commercial operations, because the carbonate, the only form in which we have it, becomes caustic under heat, and this, when left to itself, absorbs water and falls to powder. It can be used when an operation is continuous, but in no other case. In Styria the hearths and sides of blast-furnaces are sometimes made of it, but they are generally quickly abraded and make but short campaigns. Lime is infusible; bricks of it are used for the fusion of platinum. It is, however, very easily acted upon by silica, but when this is absent it is one of the most refractory substances known.

Magnesia made from the carbonate by driving off the carbonic acid is very refractory, if pure. It is made into any shape that is required, and is one of the most refractory of substances. It was formerly very difficult to get the carbonate of magnesia, but large quantities of it have been found on the island of Eubea. It can be calcined at a less cost than ordinary lime, losing half of its weight, so that if calcined before it is transported, the cost may be still further reduced. It contains a little lime, silicates of iron, and some serpentine and silica. After calcination the serpentine and silica can be separated, as it is easily crushed, but the most of the work can be done by hand-picking beforehand. Before moulding, it must be submitted to about the temperature it is to undergo in the furnace, otherwise it would contract. It is then mixed with a certain portion of less calcined material, which is one-sixth for steel fusion, and 10 to 15 per cent. water by weight, and pressed in iron moulds. If for any reason, either because there was too much or

too little water, or because the material was not properly mixed, or contains silica, the crucible is not strong enough, it has only to be dipped in water which has been saturated with boracic acid, and then heated.

Bauxite is one of the natural substances which has been recently applied as a refractory material. It is a compound of silica, alumina, and water. Like all aluminous substances, it has the advantage of tending to form aluminates which are less fusible than silicates, and are generally completely infusible at commercial temperatures. It does not have a very constant composition, as silica is sometimes not even present at all, as is shown by Berthier's analysis given below :—

TABLE V.—ANALYSES OF BAUXITE.

	Berthier.	Deville.	School of Mines.
Al^2O^3	52·0	58·1	60·00
Fe^2O^3	27·6	3·0	0·80
SiO^2	..	21·7	23·00
HO	20·4	14·0	15·00
TiO^2	..	3·2	..
Total	100·0	100·0	98·80

Dr. Siemens states that a series of experiments to form solid lumps by using different binding materials have shown that 3 per cent. of argillaceous clay suffices to bind the bauxite powder previously calcined. To this mixture about 6 per cent. of plumbago powder is added, which renders the mass practically infusible, because it reduces the peroxide of iron contained in the bauxite to the metallic state. Instead of plastic clay as the binding agent, waterglass or silicate of soda may be used, which has the advantage of setting into a hard mass, at such a comparatively low temperature as not to consume the plumbago in the act of burning the brick. When the lining is completed, the interior of the bricks is preserved against oxidation by fluid cinder, added to bind them together, which also prevents contact with the flame. A bauxite lining of this description resists both heat and fluid cinder in a very remarkable degree, as was proved by lining a rotative furnace partly with bauxite and partly with carefully-selected plumbago bricks. After a fortnight's working the brick lining was reduced

from 6 inches to less than half an inch; whereas the bauxite lining was still 5 inches thick and perfectly compact. It is also important to observe that bauxite, when exposed to intense heat, is converted into a solid mass of emery of such extreme hardness, that it can hardly be touched by steel tools, and is capable of resisting mechanical as well as the calorific and chemical actions to which it is exposed. The bauxite used for this lining was of the following composition:—

Alumina	53·62 per cent.
Peroxide of iron	42·26 "
Silica	4·12 "

Almost all the aluminates of iron are infusible. Siemens has taken advantage of this, to make bauxite bricks, which have this composition:—Alumina, 50 per cent.; sesquioxide of iron, 35 per cent.; silica, 3 to 5 per cent. They last five or six times as long as the best Stourbridge bricks. Nothing has yet been found which resists the corrosive action of basic slags so well.

The materials of which fire-bricks are generally made, however, are fire-clays, which are hydrated silicates of alumina, containing from 50 to 65 per cent. of silica, 30 to 75 per cent. of alumina, and 11 to 15 per cent. of water. The relation between the silica and alumina is exceedingly variable, owing to the fact that a part of the silica, which is not always the same, is combined and a part uncombined. The quantity of water is also variable, as part of it is hydroscopic and can be drawn off without injury to the clay. The plasticity generally depends on the water of combination, which, when driven off at a red heat, cannot be made to combine again, so that this property is then entirely lost. Fire-clay contains, beside, a small quantity of elements, such as potash, soda, lime, magnesia, and iron, and is generally less refractory, as it contains more of them. When it contains from 6 to 10 per cent. it will generally melt. When the clay is silicious, 3 to 4 per cent. of other substances makes it fusible. When it is aluminous, 6 to 7 per cent. of oxide of iron does not make it lose its refractory qualities, owing to the very refractory nature of most aluminates. When, therefore, the corrosive effects of basic slags are to be feared, aluminous clays must be used.

Almost all clays contain organic matter; if it is present alone it makes the clay more refractory, since the presence of even a small amount of carbon tends to increase its resistance to heat, as seen in graphite crucibles. Pure material composed exclusively of silica and alumina would be completely infusible. Such material is, however, exceedingly rare. The property of infusibility is always more or less compromised by the presence of foreign substances, which tend to damage it or take it away altogether. The clay, which according to Brongniart is the most refractory when deprived of its hygrometric water, has the composition: silica, 57·42; alumina, 42·58.

While the refractory nature of clay is due, to a very great extent, to its chemical composition, it is not due to it alone. There are, probably, no two beds of clay in the world, or distant parts of the same bed, that have exactly the same composition, and yet they may be very nearly of the same quality. The power to resist heat is, undoubtedly, owing in part to the molecular condition of the particles, a subject which has been but little studied, and is but little understood. Many clays, which would be rejected from chemical analysis alone, are sometimes found in practice to be excellent refractory materials. It has been found that the refractory nature of the clay depends also to a great extent on the mechanical arrangement of the particles, for of two materials having exactly the same chemical composition, one being coarse, and the other in a fine powder, the coarse may be practically infusible, while the fine may be more or less easily fusible. The more porous the same substance is, the more infusible it will be. It may be said in general terms that the value of a given refractory clay will be inversely as its coarseness and as the amount of iron contained. When the amount of iron reaches 5 per cent., the material becomes worthless. This is true, however, only in general, for Pettigaud cites an excellent clay from Spain, in which there is 25 per cent. of iron. This is, however, an exception, and will be referred to again.

In order to be useful, clays should be, or should be made to be, more or less plastic, as this property is necessary to their being moulded into the many shapes required. This plasticity is owing to the fineness of the particles, to the presence of alumina, and to

the water of combination. It is diminished by the presence of iron, lime, and magnesia. The refractory nature of the clays, then, is due to the presence of alumina, and to the absence of potash, soda, lime, magnesia, and iron. The characteristics of all fine clays may be said to be that they do not effervesce with acids, that they make a paste with water, which is absorbed so rapidly as to make a slight noise. This paste can be drawn out without breaking, and is very plastic. Dry, they are solid, and break into scales when struck. They have a soapy feel, are scratched or polished by the nail, can be cut into long ribbons with a knife, and appear somewhat like horn. When fresh from the quarry they have a more or less fœtid odour, owing to the presence of some decomposed organic substances. In composition they contain, as we have seen, either silica or alumina in excess. Silica in excess makes them rough, and takes away most of their plasticity and tenacity; alumina makes them very plastic; magnesia makes them very unctuous, and almost soapy, but does not make them fusible; lime makes them dry and fusible; iron and other substances change their colour, and, beyond certain very restricted limits, make them fusible. The grey and brown colours, up to black, are owing to a small percentage of bituminous material. White clays are generally considered the best, but there is no certainty about it, as they often crack, or even melt. It is generally an excellent sign when they leave unbroken lines when scratched by the nail. It is, however, never safe to judge by the eye or the touch, as some of their chief characteristics apply equally well to materials not in the least refractory, and even those that are peculiar to them may be taken away by improperly drying them, by carelessness in storing or handling them, or by allowing them to become mixed with other substances. A preliminary analysis gives only a general idea of their nature, but it is not always a safe guide to the manufacturer, who needs first an analysis and then an assay, for some of the most inferior clays, if we should judge by their analysis, give excellent results when used as mixtures. Analysis is necessary both before and after the assay, but there is a molecular force which seems to have more to do with the value of the material than the chemical composition. The greater this force is, the less likely the heat is to overcome it, either to cause

disintegration or chemical union. If possible to do so, all clays should undergo some process of preparation with a view of purifying them.

Every person using clays should endeavour to get a certain knowledge of their properties by assay. There have been a number of these assays published. The two simplest and best are the one proposed by Bischoff and the foil assay.

Bischoff's assay is based on the comparison of every clay with one from Garnkirk, in Scotland, which is taken as a type. For this purpose the clay to be examined is mixed with one, two, three to ten parts of quartz. It is then raised to a known temperature and compared. If the clay, with three parts silica, acts like the Scotch clay with one, it is called three, and so on. The best and simplest assay seems to be one made by the blowpipe, which consists in mixing a small quantity of clay with water, and then spreading it out carefully on a piece of platinum foil in a very thin sheet, which, when completely dried, is submitted to the flame and compared with clay of known fusibility prepared in the same way.

Very few clays can be used as found. They must be, as it were, suspended in some fusible material, which will prevent, as far as possible, the mechanical effects of the heat, and allow at the same time of a certain amount of expansion and contraction, while preventing both in too great a degree. These materials are generally called "lean," that is, they do not make a paste with water, and require some binding material to keep them together. They are usually quartz sand or pulverized quartz, burnt clay, old bricks, serpentines, talc, graphite in powder, and not infrequently small coke, when the ash is not to be feared, and when graphite either cannot be had, or cannot be used on account of its high price. Some few clays from Spain contain this material, which comes from the decomposition of talc shale in which they have been suspended by nature, but this is a rare exception. The mixture must generally be made artificially.

Of all these substances quartz sand is the cheapest, but it has been found by experience that round grains of sand are less liable to become thoroughly incorporated with the binding material than the angular pieces of crushed quartz, so that when a very refractory material is required crushed quartz is always used. As the clay

contracts, the quartz expands, consequently a mixture may be made which will not change its form; but in a given case this may not be the best mixture for a special use. If the material has only to resist great heat, an excess of quartz is preferable; but if it must also resist the corrosive action of basic slags, clays burnt at a high heat, graphite or coke can be used. When the mixture is made in the place where it is to be used, without previous burning, it is generally made of one-fifth plastic clay and four-fifths burnt clay or quartz, or one-fourth lean clay and three-fourths burnt clay or quartz. This is done to avoid contraction. It is a most economical construction, even in blast-furnaces, and is coming more and more into use.

The clay, when mined, is left exposed to the air under sheds, and is cleaned and carefully dried, and is afterwards mixed with the substances with which it is to be incorporated, which are classified by numbers, varying according to the size of the sieve-holes through which they will pass. The quantity and quality of the mixture will determine the refractory nature of the material to be produced. A friable paste with large grains, and quite porous, resists a great heat. One with fine grains close and compact splits at a high heat, especially if it is not homogeneous. The manner in which the mixture is made also influences the quality of the brick quite as much as the material. In some works in Belgium, after taking all the ordinary precautions to make the mixture perfect, it is submitted to a succession of shocks continued for some time, until it is found by experiment that the materials are perfectly mixed. It has been found by long experience that the bricks so made kept their form perfectly, while others made of exactly the same mixture in the ordinary way contract.

The quantity and size of the mixture depend upon the size of the article to be manufactured. When coarse grains are used, greater thickness must be given to the sides of the articles if they are hollow, and they must be made larger if they are solid, thus giving a mechanical cohesion where a chemical one is wanting. The usual quantities of the mixture are two-fifths to two-thirds of the substances added to two-fifths to one-third of the clay, these quantities being determined by volume and not by weight. When coke-dust is used it does not seem to have any decided effect

beyond one-tenth. The action of coke or graphite is to decompose the metallic oxides as they form, and thus prevent their union with the material of the crucible. Coke may be profitably used in the place of graphite when the ash is in small quantity, free from iron, and highly aluminous. Beyond 2 to 3 per cent. graphite cannot be profitably used, as it weakens the article and renders it liable to break. The mixture which gives the very best results for small objects is, however, worthless for large. It will generally be found that the pieces which crack up and down in drying have had too much material mixed with the clay, and those which crack laterally have had too much clay.

The very greatest importance is attached in some industries to not having a mixture made by a machine. In most places even to this day the inhuman method of heel treading is used, because, either from the fact that more care is exercised, or because smaller quantities are mixed at once, better results are obtained. The more the operations of mixing are repeated, the better the material, and it is undoubtedly true that with mechanical means such a homogeneous paste is not produced as can be made by human labour, because the whole object of the machine is to operate on large quantities at a time.

The paste made, and the article completed, it must be dried or "tempered." This is commenced in the open air, and if possible out of the draught. If the draught cannot be excluded, the place where the drying takes place is slightly heated, commencing at a temperature from 60° to 70° Fahr. and keeping it up from twenty-five to thirty days, then increasing it from 80° to 100°, leaving the article as long as possible, an active ventilation but the same temperature being kept up. The article should remain in a temperature of from 150° to 180° for at least six weeks. Bricks do not generally require such care; but crucibles and retorts do. Long experience has proved that there is a great economy in conducting this process of tempering as slowly as possible, and that it influences materially the refractory nature of the article.

It is found by actual experiment in crucible works that those crucibles made from the same mixture, tempered during six to eight months, last more than three times as long as those which have been tempered only two; so that in general the older the

article before being burned the better. This desiccation, while perhaps it is the most important part of the manufacture, is undoubtedly the one most neglected. A poor article, well tempered, is often better than the best which has been hastily dried. By working rapidly and filling up cracks as they form, in a too rapidly heated drying house, with a very liquid material, in order to secure complete penetration, both time and money are lost. The material never lasts nearly so long as when slowly dried. In the works at Andenne, in Belgium, large pieces, like glasshouse pots, are kept six months in the drying house before they are burned, and during this time the greatest care is taken to prevent any air colder than the drying room to strike them. Leaving the door of the drying furnace open has been known to crack the pieces, which had been up to this point most carefully prepared and tempered.

In reviewing the effects which the different elements which constitute refractory materials have, we find that the same element often produces exactly contrary effects, according to the proportion in which it is present, and that there is nothing anomalous in those effect being so produced. Silica causes expansion when highly heated, so that the mould for shaping bricks must be smaller than the brick is to be. Every mixture has its own particular rate of expansion and contraction. This expansion not only takes place when the bricks are made, but if, when used, they are submitted to a higher degree ot heat, they expand still further, and contract on cooling to such an extent that at Dowlais the tie-rods of the steel furnace are slackened when the furnace is getting into heat, and are tightened again as it cools. At Crewe, this is made self-acting by means of springs. At Creusot the furnace casing is made so strong as to resist the pressure, so that the centre of the roof arch must rise and fall, to allow for the expansion and contraction. When neutral brick must be had for any reason, it is mixed with just enough clay and burned brick to make it keep its form, and such a brick is generally less fusible, and contains less silica.

Alumina alone, or with silica to the proportion of 30 to 38 per cent., is very refractory, but 3 per cent. of it in a silica brick makes it fusible. In clay, or pure silica, it tends to contract, and this tendency is greater as the alumina is in greater quantity, and the heat of manufacture has been low; but when it has been very

highly heated at first, it undergoes but little change. Though both silica and alumina affect each other unfavourably, Bischöff found that 4 of alumina to 1 of silica, or 2 to 1 or 1 to 1, only splintered before the oxyhydrogen blowpipes, making masses with a granular fracture. One of alumina to 2 of silica was fusible like porcelain, but somewhat granular. One of alumina to 4 of silica, and 1 of alumina to 6 of silica, melted like a thick enamel, which shows that the acid silicates of alumina are much more fusible than the basic. He also found that a mechanical mixture of alumina and silica was less fusible than the same amount in a natural combination, and that in general silicates already formed are more fusible than a mixture of their constituents. The general property of alumina, when mixed with other substances, is to bind them together. When combined with iron or other bases alone, it makes infusible aluminates; but if silica is present, it fuses more or less easily. It is generally considered that the proportion of alumina in a brick should be between 10, 20, and 25 per cent.

The alkalies in small quantities make a brick fusible. There is a great difference of opinion among those who have studied this subject with regard to this quality. Snelus states positively that 1 per cent. of alkalies in an otherwise good material makes it too fusible to withstand high temperatures. Riley states, with equal positiveness, that he has found brick containing 2·73 potash to resist the greatest heat of a Siemens-Martin furnace. It is probable that both are right, and that in the special cases alluded to, the peculiarities were owing to the association of elements. In any case, a material with a very small percentage of alkalies cannot be used.

Lime alone is comparatively infusible, but in very small quantities in a clay, it makes a brick fusible at very high temperatures. One per cent. of it with silica makes the most fusible brick known. Magnesia in small quantities makes the clay fusible. In very large quantities it is very refractory. Alone, it is entirely infusible.

Oxide of iron, in the absence of alkalies, may be present in small quantities without seriously affecting a clay, unless it is to be used for melting steel. If alkalies are present, any proportion of iron would make such a clay worthless. If no silica at all is present,

5 or 6 per cent. may not damage it. In a silica brick, 2 to 3 per cent. of iron makes the brick worthless. If the iron was always to remain in the state of a sesquioxide, its compounds would be more infusible, and a large percentage would do no injury; but some of the sesquioxide is certain to become reduced to protoxide in the presence of reducing gases, and the result is a very fusible compound in the presence of silica.

There is still a more deleterious and dangerous effect of iron in fire-brick, because its effects are produced not at a high heat, but at a comparatively low temperature. It is well known, since the researches of Bell and others, that when a brick containing iron is exposed, even at a low temperature, to gas containing carbon, and that part of this carbon is deposited near the iron, this has often not only caused the brick to lose its cohesion, but may even burst it, so as to throw down the iron walls of furnaces and the lining of flues. The presence of iron, therefore, is doubly to be dreaded, as its presence at low temperatures is quite as deleterious as at high.

As much as 1 per cent. of titanium has been found in some clays. Little is known about it, but it acts like silica.

Bischoff found that 20 per cent. of magnesia, 28 of lime, 47·1 of potash, or 40 per cent. of iron had exactly the same effect of making the clays fusible, and that when 4 and 2 of the different bases were used, the relation was striking and in about the same order. The quantity of other substances required to make a compound fusible depends upon the quantity of silica present; the more the silica the less the quantity.

Table VI. indicates some of the physical qualities found in English fire-bricks.

The essential qualities of a good brick may be stated as follows:—

Uniformity.

Regularity of shape.

Strength to resist the different pressures required under different circumstances, and

Its reasonable price.

No material yet manufactured fulfils all these conditions, but there seems to be no reason why, with proper investigation, a mate-

TABLE VI.—PHYSICAL QUALITIES OF FIRE-BRICKS.

Variety.	Size of Brick.			Weight Dry.	Weight Wet.	Water Absorbed.	Percentage of Water Absorbed.	Load at which Brick Cracked.	Force required to Crush Brick.	
	Length.	Breadth.	Thickness.							
	in.	in.	in.	lbs.	lbs.	lbs.	per cent.	lbs.	lbs.	in tons per sq. in.
Stourbridge, No. 1	9·20	4·41	2·54	7·153	7·807	0·754	10·542	60,144	104,944	1·154
„ „	9·18	4·30	2·46	7·178	7·837	0·659	9·180	60,144	113,344	1·281
„ Ordinary ..	9·20	4·45	2·37	7·388	8·037	0·649	8·784	71,344	127,344	1·388
„ „ ..	9·14	4·55	2·52	7·204	7·891	0·687	9·536	32,144	110,544	1·186
„ Average	..	..	..	..	..	..	9·510	55,944	114,042	1·252
Leemore Furnace	9·15	4·38	2·51	7·539	7·961	0·422	5·597	48,944	108,301	1·206
„ „	9·08	4·30	2·57	7·087	7·391	0·304	4·289	15,344	137,984	1·577
„ „ Average ..	..	..	..	..	..	..	4·943	32,144	123,144	1·391
Newcastle Fire-brick	8·90	4·40	2·42	6·173	6·837	0·664	10·756	57,344	96,544	1·100
„ „	8·93	4·40	2·45	6·120	6·675	0·555	9·068	62,944	107,744	1·222
„ „ Average	..	..	..	..	..	..	9·912	60,144	102,144	1·161
Dinas Fire-brick	8·92	4·25	2·50	6·353	6·953	0·600	9·444	32,144	107,744	1·268
„ „	8·93	4·40	2·38	6·324	6·914	0·590	9·327	93,744	112,224	1·275
„ „ Average ..	..	..	..	..	..	..	9·385	62,944	109,984	1·271
Red Welsh Fire-brick	8·65	4·28	2·65	6·586	6·990	0·404	6·134	18,704	99,344	1·197
„ „	8·64	4·25	2·46	6·447	6·850	0·403	6·250	46,144	139,664	1·698
„ „ Average	..	..	..	..	..	..	6·192	32,424	119,504	1·447

rial should not be made to fulfil the most of them. The metallurgical world is nearly agreed that the refractory material of the future must be made artificially, and that it is hopeless to look for it among natural products. No brick can come up to the modern standard of infusibility which contains 5 per cent. of iron or 3 per cent. of combined alkalies or alkaline earths; yet the most infusible brick known which in the roof of a Siemens-Martin furnace will resist during 250 charges, and then wear out by abrasion, when required to come in contact with metals, oxides, and alkalies in a spiegel cupola will hardly stand twenty-five heats, while an iron pipe coil, which is easily destroyed by heat, will last almost indefinitely in the same cupola, provided only a sufficient stream of water is run through it. If silica makes the best roof, it makes the worst hearth. Alumina, when present in very large quantities, even in the presence of a small amount of silica, makes compounds which are almost infusible, so that it should be used for the fire-bridges and hearths, and not put into the roof, where its tendency to contract would endanger the structure of the furnace.

Far too little attention has been given to the abrasive and corrosive power of coal dust and ashes carried by the draught, in gradually cutting and fluxing away the parts of the furnace exposed to its action, and many qualities of brick which are infusible in the assay, owe their small power of resistance to its effect. A brick to be used when it is exposed to such action, should always be tested by placing it for a considerable time on the bridge of the furnace where it is to be used; for the destructive effects of this almost unobserved agency seem to be greater than those of long-continued heat.

A good brick should not only resist high temperatures, but sudden changes of temperature without alteration of any kind, such as crushing and splitting, and the like; and at a high temperature should undergo the least possible change of form. Shrinking is generally due to insufficient burning or a too small proportion of old material in the mixture, and generally occurs in aluminous bricks. Its chief evil is in allowing the flame to penetrate the open joints, and give the dust an opportunity to cut between the bricks, for any cause which produces eddies in the flames, such as hollows or projecting surfaces, is certain to effect the destruction of that

part of the furnace. Silicious bricks have, on the contrary, a tendency to expand under the influence of heat. This is true to such an extent, that in the steel furnaces where they are used, provision must be made for slackening the tie-rods when the fire is being raised, and tightening them when it is being cooled.

The crushing weight of an ordinary fire-brick when cold is from 600 to 1000 lbs., but some of the best have been known to resist as high as 3000 lbs. to the square inch. To ensure the safety of the structure and the success of the process, it should not only retain its power of resistance, but should not undergo any change of form, or soften materially under long-continued heat, and at the highest possible temperatures should support more than double the strain required without alteration. In the walls of the fireplaces, those bricks will be best which are dense, and contain an excess of silica. In the hearth they should contain an excess of alumina. In the arch they should be nearly pure silica, alumina, or magnesia. Bricks in a roof give out from shrinkage, cracking, or splintering; splintering takes place when silicate bricks are made of impure mixtures, usually from too much fine material and bad burning. Bricks which are liable to splinter are generally cross-grained and dense, with a small conchoidal fracture when made from improper mixtures, and when, from improper burning, they ring like a cracked vessel. All good bricks wear off evenly.

No matter how good a material may be, if its price is so high as to prevent competition, it might as well not exist. Hence any effort to furnish a good material should have for its aim to produce it at the least possible cost.

In discussing a refractory material in a given locality, there is to be taken into account:—

The clay and other materials to be had;

The ore or metal to be treated;

The fuel to be used; and

The foreign substances in the gangue of the ore or metal.

Whether to use one clay or a calcined or raw clay, must be determined by direct experiment, and then the size of the grains of the mixture for the given use must be determined, for each substance is more or less refractory according as it is coarse or fine. Thus, in Belgium, a porous material with a large grain is used for

blast-furnace brick, but a fine material with a close grain for coke furnaces. It must then be ascertained whether the mixture contracts or expands, for clays expand between $\frac{1}{32}$ and $\frac{1}{8}$th. The ways in which the material tempers must then be carefully studied. It is not sufficient to have only a good material, for almost as much depends on the manipulation as upon the material itself. To temper properly, the clay and the manufactured article should both be dried gradually and uniformly. It must be fired evenly, and the temperature slowly raised to the proper point. The brick or other material once made, should be kept from dampness, as it is porous, and likely to absorb moisture, and should be heated before being used in the furnace, and put in at a high heat. If it is to be put in blast at once, especially with silica bricks, the temperature should be as high as the hand can bear. If the furnace is to be a long time standing, this precaution is unnecessary; but in the two last cases the furnace must be dried very carefully and slowly. No brick which has been dressed should ever have the dressed face exposed to the flame. Without the observation of these precautions, a very good brick may have a very bad result. It is too much the habit of this age to get quick results, and this has led some blast managers to boast that steam was issuing from the top of their furnace, while cast iron was being tapped from the bottom; but under such management we never hear of long campaigns, but very frequently hear of disasters.

It is thus seen that a brick that is good for the cupola would be worthless for the reverberatory furnace, that which answers well for iron generally would be worthless for zinc, and a crucible which is excellent for steel cannot be used for brass. It is the way to realize progress, to analyze natural substances until we find the right one, or make repeated trials, and depend upon them alone. All investigations go to show that we should look for artificial and not for natural compounds, and that when we have made a mixture that has stood well, we are then to examine and analyze it in order to reproduce it. Failure in this, as in many other cases, is very often owing to wrong application of good materials rather than fault in the materials themselves.

CHAPTER IX.

CRUCIBLES.

CRUCIBLES are vessels used for the fusion of certain metals, for assaying, and generally for many other chemical purposes in which intense heat is employed.

The use of the crucible appears to have originated with the old alchemists, who were in the habit of marking them with the sign of the cross, before commencing their operations; whence the derivation of the name. The principal requisites of a good crucible are, that it should be capable of enduring the strongest heat without becoming soft or losing much of its substance; that it should not crack on being exposed to sudden alternations of temperature; that it should withstand the corrosive effect of the substance fused in it; and, lastly, that it should be sufficiently strong to support the weight of the molten metal when lifted from the furnace.

Crucibles which become tender at a high temperature are then liable to break or crumble when grasped with the tongs, and are very dangerous.

Clay crucibles are made of fire-clay, mixed with silica, burnt clay, or other infusible matter.

In order to counteract the tendency clay has to shrinking at high temperatures, the other substances are mixed with it. The proportion of burnt to raw clay may be varied, but two-thirds raw clay to one-third burnt clay is a very common proportion. It is necessary that there should be a sufficient quantity of raw clay to produce the proper degree of plasticity for working.

The unburnt fire-clay must be ground, as must also the burnt clay, the latter generally consisting of old crucibles or glass pots, which have been exposed to high temperatures. The surfaces of these old pots must be cleaned from all extraneous matter, and their vitrified coating be chipped off.

Clays which contain a maximum quantity of pure silica are best adapted for the most infusible crucibles, if in addition they are comparatively free from such injurious admixtures as lime or iron; and the infusible properties can be strengthened by additions of burnt clay, such as we have indicated, or of powdered coke and plumbago.

The celebrated Berlin crucibles are made from 8 parts fire-clay, 4 parts black-lead, 5 parts powdered coke, 3 parts old ground crucibles. Another mixture is 2 parts fire-clay, 1 part ground gas-coke.

The materials should be as free from lime as possible, well kneaded together, and slowly dried in a kiln.

When fire-clay is not easily obtainable, as a substitute for it steep common clay in hot hydrochloric acid, wash it well with hot water, and dry it.

The crucibles in most common use in Birmingham and its neighbourhood, as well as in Sheffield, are made of a fire-clay found near Stourbridge, which is generally mixed with some other substance, such as powdered coke, in order to lessen its tendency to contract when strongly heated. The following are about the average proportions: 4 parts fire-clay, 2 burnt clay cement, 1 ground coke, 1 ground pipeclay. These Stourbridge clay crucibles, or casting pots, are only carefully dried, but not burned until required for use, when they are put into the melting furnace first with the mouth downward, and when red hot are taken out, and put in again with the mouth upward.

The melting pots or crucibles employed by Mushet in the manufacture of cast steel, or homogeneous metal, were made by mixing kaolin or china clay with black or grey fire-clay from the coal measures, and pulverized old pots, the clays being passed through riddles having 64 to 100 meshes to the square inch. The proportions used by Mushet are 5 parts by measure fire-clay, 5 parts kaolin, 1 part old pot, and 1½ parts of coke-dust; the ingredients being well mixed, and then kneaded, tempered, and moulded in the usual way.

The material from which the most refractory crucibles are now made is plumbago, or black-lead. This is one of the various forms assumed by carbon, and in its pure state is nearly identical in

composition with the diamond, although so very different in its structure and physical character. Until a few years ago the use of black-lead, or plumbago, pots was exclusively confined to melters of precious metals, but they are now employed for melting all descriptions of metal; and large numbers of them are used by the brass-founders and others.

In making the crucibles, the materials, consisting of about one part fire-clay to two parts plumbago, are first ground to powder and sifted, after which they are mixed, the clay being added to give a sufficient degree of coherence and plasticity.

The advantage claimed for plumbago crucibles is that they are durable, and that they effect a great saving of time, labour, and fuel; but on the other hand, an objection to black-lead pots, independent of their cost, is that they are unsafe for the workmen. A clay pot, at steel melting heat, is as tough almost as leather; it may be beaten flat, but cannot be broken; while a black-lead pot remains brittle at any heat, and the puller out or the teamer can never feel quite sure, in handling a partly worn-out pot, that it may not be crushed under the pinch of the tongs.

Krupp, at his famous Essen factory, uses plumbago for his steel crucibles. Each crucible is only used for one melting, after which it is ground up, and used over again for the manufacture of new crucibles, with the admixture of a certain proportion of fresh plumbago.

When it is necessary to protect a crucible from the corrosive action of the material to be melted in it, it can be lined with charcoal powder, or black-lead. In a small crucible, the powder may be made into a paste with a little gum-water or treacle, and rammed into the crucible, the central cavity being afterwards shaped by a small rammer of the desired form.

For larger crucibles a mixture of anthracite powder, or powder of gas-retort carbon, or gas-tar, may be employed.

To test crucibles as to power to resist corrosion, protoxide of lead, or a mixture of protoxide of lead and dioxide of copper, is melted in the crucible. If a clay crucible is not permeated or corroded by this mixture to a sensible extent after a short time, it may be considered capable of resisting all ordinary corrosions in practice. As a rule, clay crucibles resist permeation and corrosion

in the proportion of the fineness and regularity of grain, but their tendency to crack is increased in the same rate.

Cornish crucibles are principally used for assaying copper; they are made of a clay found in some parts of Cornwall, and the smaller sizes are capable of resisting sudden alternations of temperature, a quality which is probably due to the large proportion of silica mixed with the clay, but they are rapidly corroded by melted oxide of lead.

Hessian crucibles were formerly employed to a much greater extent in metallurgical operations than they are at present. They are made principally from a clay found at Gross-Almerode, and in their composition resemble very closely the Cornish crucibles. The form is triangular, and they are generally packed in nests of six; the smaller sizes fitting into the larger. These crucibles are tolerably lasting at moderate temperatures, but are apt to fuse when exposed to very great heat.

Several kinds of French crucibles are manufactured, some of which are of very excellent quality, especially those of Beaufay, called the creusets de Paris, and those of Deyeux, termed creusets de Saveignies. Both kinds, however, contain a large percentage of oxide of iron, which renders them objectionable for some purposes.

London crucibles are of a reddish-brown tint, very close grained, and capable of resisting the corrosive action of oxide of lead, but liable to crack when suddenly heated. They are made of various sizes, from 2¼ inches up to 8½ inches in height.

For special metallurgical or chemical purposes, crucibles are sometimes composed of platinum, lime, bone-dust, magnesia, pure carbon, and other materials.

Crucibles are made of various forms and sizes, according to the kind of work for which they are intended; those used for assaying are scarcely larger than a lady's thimble, whilst others made for zincing shot will hold as much as 800 lbs. of molten zinc. Some are nearly cylindrical, others triangular, and others skittle-shaped.

Fig. 2, Plate XXI., shows the pot and cover employed in melting steel, while Fig. 3 is a common form of crucible for brass and the like. Small crucibles are generally kiln-burnt before being used, larger crucibles are usually dried gradually in hot stoves.

Where the crucibles or pots, as they are familiarly termed, are

made of fire-clay and upon the works, the pot flask, or mould, and plug are commonly of the form Figs. 3 and 4, Plate XXII. The pot mould is of cast iron, with two ears cast upon it to lift it by. Its inside is the shape of the outside of the pots; it is turned smooth, and is open at the bottom as well as the top. There is a loose bottom made to fit, but not so small as to pass through; this has a hole in the centre, three-quarters of an inch in diameter. When in use it stands upon a low post firmly fixed in the ground, which also has a hole 5 or 6 inches deep in its centre. The plug which forms the inside of the pot is of lignum vitæ, it has an iron centre which projects through it about 5 inches, corresponding in size with the hole at the bottom of the mould.

The clay for a steel pot weighs about 24 lbs.; it is moulded upon a strong bench into a short cylinder, and the inside of the mould having been well oiled, the clay is dropped into it, and the plug, also oiled, forced into the clay, while the projection finds the hole in the loose bottom in the centre of the mould, which guides the plug. The plug is driven down 2 or 3 inches by the blows of a heavy mallet on the top of the iron head; it is then taken out to be oiled again by putting a piece of round iron through the hole in the iron head to lift by, giving it at the same time a screwing motion. It is then driven by the mallet, while the clay, rising up between the plug and the mould, reaches the top. The clay is cut even with the top of the mould by passing the knife round between it and the flask or mould several times, holding it inclined towards its centre. The mould is now taken and set with its loose bottom upon a small post fixed in the floor, and the mould gently allowed to rest upon it. This pushes up the bottom with the pot upon it; and the hole being filled with a bit of clay, the pot is finished. When the pots are sufficiently hard to bear handling, they are placed to dry upon rows of shelves against the flues in the furnace, where they remain from ten to fourteen days, and before use they are annealed by being placed from seventeen to twenty hours in a special annealing furnace, and they are taken directly from this and placed for use hot into the melting furnace.

Crucibles are frequently made on an ordinary potter's wheel, and special machines are also employed for the same purpose. One of these, T. V. Morgan's machine for making either large or small

crucibles, is illustrated by Fig. 1, Plate XXI., and Figs. 1 and 2, Plate XXII. The peculiar mechanical arrangement consists in fitting the former, or forming tool employed in the apparatus, so that in addition to being capable of an up-and-down movement, the former is free to be moved and adjusted horizontally as the crucible is being moulded, and according to the required size or thickness of the crucible.

When a crucible is to be made the frame is pulled down to cause the former to enter the plastic material, which is placed in a mould, on a revolving lathe or jigger, as usual, and when the former reaches the bottom of its course, a catch on one of the uprights secures the frame in position. The threaded rod is then turned, to cause the former to move horizontally, and spread the plastic material against the side of the mould. Finally, the back end of a lever carried on the top of the frame, and free to move backward by means of slot or otherwise, is inserted into a hole formed for the purpose, and its forward end is pressed down by hand, so that the lever bears forcibly upon the frame, and prevents all vibration or movement of the former. When the crucible is finished, the handle is turned to bring the former to the centre of the crucible, the lever is moved forward out of its hole, the catch released, and the frame raised up by a balance-weight. The operation is then repeated for the next crucible, and so on.

Fig. 1, Plate XXI., is a front elevation; Fig. 2, Plate XXII., a side elevation; and Fig. 1, Plate XXII., a section through the line A A of Fig. 1, Plate XXI., of Morgan's apparatus. *a* is the former, or forming tool; it is fitted to a block *b*, which is, as before stated, free to be moved horizontally in a frame *c* by means of a screw *d*, taking into a corresponding thread in a nut in the block *b*; the ends of the screw *d* work in fixed nuts on the frame *c*, and the right-hand end is provided with a handle *g*, which is turned according as the former *a* and block *b* are required to be moved. The frame *c* is free to move up and down in slots *h*, formed in two uprights, and its weight is counterbalanced by weights *k k*, on the end of chains or cords passed over pulleys and connected to the frame. *n* is a catch on the upright to secure the frame *c* in position when the former *a* reaches its lowest position. *o* is the mould into which the plastic material is fed; this mould is carried on an

ordinary lathe or jigger *p*, to which rotary motion is imparted as usual. When the frame *c* is caught by the catch *n*, and the mould is caused to rotate, the screw *d* is turned by its handle *g*, so as to cause the former *a* to move horizontally, and spread the plastic material against the side of the mould, and when it has been moved to the required distance, which is regulated by a scale on the frame, the back end of a lever *q* carried on the top of the frame and free to move backward by means of a slot *r* is inserted into a hole *s* formed in an upright, and its forward end is then pressed down by the attendant so that this lever bears forcibly upon the frame *c* and prevents vibration or movement of the former. When the crucible is finished, the handle *g* is turned to bring the former *a* to the centre of the crucible, the lever *q* is moved forward out of its hole *s*, the catch *n* is released, the frame is raised up, and the mould is removed in the ordinary manner; all being then ready for the next operation. *u* is a horizontal bar under the platform *v* and hinged at *w*, while its front end extends to the front of the apparatus. *x* is a block on the bar *u*, and *y* is a collar on the lathe-shaft. When it is required to stop the revolution of the lathe, the attendant moves the bar *u* on its hinge *w*, so as to bring the block *x* against the collar *y*. *z* is a horizontal bar or guide for the bar *u*.

In the present day the consumption of crucibles is very large; they are extensively employed by the brass-founder, the gold and silver refiner, the manufacturers of cast steel and gun-metal, as well as in the melting of zinc and copper, in the various operations of the analytical chemist, assayer, and in the production of the coinage of different countries.

CHAPTER X.

BLAST—BLOWING ENGINES, FANS, AND BLOWERS.

It is desirable that the blast for cupolas should be adequate in quantity and pressure for the perfect combustion of the fuel, but not greatly in excess of what is needed for that purpose; it should be delivered as free from moisture as possible, and in a perfectly uniform stream.

The pressure of blast required varies according to the nature of the fuel employed; it is seldom that a greater pressure than from 2 to 3 inches of mercury is necessary, and with soft coke a much lower pressure will suffice.

If only for the purpose of supplying perfectly dry air to the cupola, it would be advantageous to heat the blast on its way from the blowing engine or fan, but by still further raising the temperature of the blast by passing it through regenerative fire-brick stoves, a considerable economy in fuel would be obtained per ton of iron melted, without any deterioration in its quality taking place. Blast heated in this manner can be readily brought to a temperature of 1300° Fahr., or can easily be regulated to any lower temperature desired.

The blast may be obtained by means of either blowing engines, fans, or blowers, any one of which answers the purpose as to quality and quantity of air supplied; questions of cost and convenience principally govern the selection of the power to be employed.

Sometimes manganese or other reagents are blown into the cupola, when the iron is required for chill castings; it will be easier to send these into the cupola by means of the blast cylinder than by a fan.

The supply of blast must be regulated as to intensity of pressure and quantity.

If a "cutting" blast is employed of too high a velocity, it will blow away a considerable quantity of small unburnt fuel.

If the blast is too "soft" or feeble, much of the fuel will be burnt without doing its duty, and if the pressure was allowed to fall below a certain amount the furnace would consume an almost unlimited amount of fuel, without at any part attaining the melting point of cast iron.

The quantity of blast necessary for any given cupola depends upon so many varying and disturbing elements that experience and judgment must be mainly relied upon to estimate it. The effects of the blast are by no means difficult to observe; if there be too small a supply imperfect combustion will result, if the supply is too large the consumption of fuel will be increased, and much of its heat will be wasted, being carried away too rapidly through the cupola.

Well-made blast engines with double cylinders and double-acting blast cylinders give much more economical results as to useful effect derived from a given power, than can be obtained with the best possible fan.

General Morin made some experiments on the duties of fans, and in one instance with blast of low pressure driven through long passages he found that the useful effect of the fan was less than 0·07 of the steam power required to drive it.

The quality of the iron is much influenced by the quantity and intensity of the blast; if these or either of them are deficient, an inferior pig iron may give off sulphurous fumes, run thick and pasty, and make bad or inferior castings, whilst the same iron with more favourable conditions as to blast will probably lose much of its sulphur in the melting, and when tapped will turn out tolerably workable iron.

Any description of apparatus which will give the requisite volume and pressure of blast with regularity can be adopted without in any way affecting the quality of the iron; but there are numerous other considerations to be studied as to the selection of the apparatus, such as first cost, economy in working, power required to drive, compared with duty in the shape of useful blast yielded, convenience for position, and safety.

The Tromb, or waterfall blast machine, such as is used in France and Germany, is an efficient blowing machine, but it is only available when there is a regular and abundant flow of water, with a

considerable fall. This source of power is not often found in England, but in other countries it has been largely applied, although the blast obtained by its use is generally completely saturated with moisture.

The tromb is a cheap and simple apparatus to construct, and when the water supply is satisfactory will give a good pressure of blast. It is therefore well adapted for use abroad or in the colonies, where machinery is costly, as the whole apparatus can be made of wood, consisting as it does merely of a vertical tube, and a large separator below in the form of an inverted tub.

Blowing Engines are now made by many eminent engineering firms, and all that is necessary for a proper estimate is information as to the quantity of air required per minute, and the usual working pressure.

The old-fashioned single blast cylinder is almost superseded, on account of the difficulty experienced in obtaining a regular blast, although this failing may be remedied by having a regulator or reservoir of sufficient size provided, with a loaded piston.

Horizontal cylinders, each double acting, and arranged in pairs, are frequently used for the Bessemer process, and give a powerful blast. If well proportioned they are economical, and work quietly and steadily.

Three single-acting cylinders, with a fourth cylinder acting as a regulator, also give an uniform and powerful blast, but are more expensive in first cost.

Blowing engines have the great advantage over fans, that the pressure and volume of blast is much more under control; but in nearly every case where they are employed, it is necessary to have a "regulator," so as to obtain an uniform flow of blast.

It is advisable to have two complete sets of horizontal engines and blast cylinders, discharging into a large dry regulator, and supplied with steam from boilers of such strength and capacity as to be able to give ample high-pressure steam for any work the engine can ever be called on to perform.

Such plant is necessarily somewhat costly, and in small works, or in new works where the capital is limited, fans, or blowers, will be generally preferred, as much less expensive than blowing engines.

Figs. 1 to 4, Plate XXIII., represent forms of common fans. In general they consist of a central spindle, upon which are hung from four to six arms, meeting on an eye at the centre, through which the axle is passed, and by which they are fixed to the axle. Upon each of these arms a blade generally is fixed, by rivets or bolts; the assemblage of blades constitutes the propelling agents. To render them effectual they are encased in a round box, adapted to them, having a central opening each side, for the admission of air, and an opening in the circumference for the expulsion of air, with a short passage in continuation, to connect the air-passages leading to the furnace. This case should be strong and heavy. By the rapid revolution of the blades upon this axle, a strong current sets in at the centre, and is propelled along the air-passages to the cupola. The journals of the axles should be long, with the view of dispersing the great amount of friction to which they are subjected, by running in their bearing at such a high velocity as is usually communicated to the axle. Unless these parts be very well fitted, and the framework of the arms and blades perfectly balanced and firmly fixed upon the axle, the greatest difficulty is experienced in preventing the firing of the rubbing parts. It is easy to see that if there be a very slight want of equilibrium in the machine, or, in other words, if the centre of gravity of the moving parts does not lie in the axis of revolution, there will be an amount of centrifugal force created during revolution proportional to the eccentricity, which must be borne by the axle.

Lloyd's Fan is shown in the vertical section, Fig. 7, and plan, Fig. 8, Plate XXIII. The outer case is cast in four parts, the two upper of which are bolted permanently together, and also the two lower. The horizontal joint through the centre admits of access to the internal parts without disturbing the foundations. S S are the bearings, and T the driving pulley. U is the internal revolving case, called the impeller, having sheet-iron discs V V fixed on the side edges of the blades. X X are turned brass rings fixed on the discs, and fitted up against cast-iron rings bolted on the outer case, forming the centre opening through which the air enters the fan. Y is the discharge pipe, and Z Z the feet on which the machine stands, and by which it is bolted down to the foundations.

The difference between this fan and those of ordinary construc-

tion consists in the form of the internal part U, which may be described as a revolving case, having six curved arms cast in one piece; on these are screwed curved sheet-iron blades, of the form shown in Fig. 7, on the outer edge of which are fastened the sheet-iron discs V V, previously mentioned. The total area of the openings at the circumference, as also the total sectional area of the internal passages at any distance from the centre, is equal to the areas of the two central openings in the sides of the outer case.

C. Schiele's Fan has been very largely employed, and possesses a good many admirable features. It is simple in construction, requires very little to drive it, gives a good volume of draught relatively to its size, and is nearly noiseless in working. Referring to Figs. 5 and 6, Plate XXIII., it will be seen that Fig. 6 is an edge view, partly in section, and Fig. 5 is a side view with one side of the casing removed to show the interior, with the revolving portion of the fan in its position.

A is a disc, on the periphery of which blades of the form represented in the figures are mounted. The blades are supported on their backs by means of ribs F, which, with the blades A, spring from the periphery of the disc A. This disc, with the blades and their supporting brackets, may be constructed even of the largest dimensions in one solid piece, either by casting or forging. B is the spindle, on which the disc A is mounted; it runs in the bearings C; the spindle being of wrought iron, with cast-iron bushes; these bearings C are cast with and form part of the casing D, and on the top of each of them is an oil cup X, to hold oil to lubricate the spindle. The radius of the disc A is larger than that of the central openings E in the casings D for the admission of air. The casing D is formed of two halves similarly shaped, but so as to form right and left sides; each of these halves is of a curvilinear shape, curving towards the inside, and in the centre having the entrance openings E. The blades F are constructed of such a form, and in such proportion to the casing, that they gradually widen from the periphery of the disc to a point beyond the central openings in the casing. From this point they decrease in width as the casing narrows, and follow the contour of the casing; the tips of blades F terminating a short distance from the narrowest portion of the casing. Beyond the tips of the blades, the casing slightly

contracts for a short distance, so that the air, of a slower speed, and which has gone beyond the blades F, is prevented from returning, and so impinging upon them.

The following Table VII. gives a few particulars of the dimensions and work of these fans, as stated by the makers:—

TABLE VII.—PARTICULARS OF SCHIELE'S FANS.

Diameter of Revolving Fan.	Tons Melted per Hour.	Pulleys.	Diameter of Discharge.
inches.		inches.	inches.
12	1¼	3	6
16	1¾	3	8
20	2½	4	10
30	5	6	14
40	10	9	18
50	20	12	24

Fig. 5, Plate XXIV., is a cross section of Sturtevant's Fan, and Fig. 6 a side view, with the casing removed, of a smaller fan of the same construction, but differently mounted. It will be seen that twelve vanes are rigidly supported by a similar number of spokes, radiating from an axis, and having conical annular discs mounted on the same axis, the fan being driven by two belts to prevent tendency to wobbling. The air enters between the spokes around the axis, and is driven forcibly by the curved floats which span the space between the annular discs, being discharged into the peripheral chamber, whence it reaches the horizontal discharge pipe shown in the lower part of Fig. 6. Within each of the band pulleys is an oil collector H, which intercepts superfluous oil, and conducts it into the oil chamber *l*, whence it may be drawn by a faucet. The shaft S is supported in tubular bearings, sustained in brackets by means of ball joints, whereby the bearings are able to accommodate themselves to the shaft while in revolution. The oilers for the shaft are near the end, and have dripping wicks which feed the lubricant in regular quantity; the oil collectors H intercepting any superfluity as already stated. The set screws *n n* afford means for adjusting the shaft lengthwise, so as to bring the wheel to its proper position in the case. Sturtevant's fan combines many of the features of both Lloyd's and Schiele's machines, its characteristic feature being the very long bearings given to the shaft; and although somewhat complicated in construction, it

has been greatly used and deservedly popular in the United States.

Figs. 1 and 2, Plate XXIV., are side and end views respectively of H. Aland's Fan. It is of very strong and substantial construction; the vanes are so arranged that they act in effect as a double fan.

The spindles are made of steel, and work in long bearings. The discs also are made of the best charcoal iron. The tremor of the strap axis is confined to one casting, by the bearing standards being cast in one of the lower parts of the fan casing. The casing is also divided horizontally, as shown in the engravings, to facilitate the operation of cleaning, without disturbing the foundations.

In fan machinery, simple as it is, we have observed that in some instances monthly and even weekly repairs have been incurred, in consequence of the want of exact balance among the parts of the fan upon its axle. With careful management in the first construction, this source of annoyance may be entirely removed. Another great fault consists of injudicious methods "of bringing up the speed" with too great rapidity, with a view to which it was certainly necessary to make use of as few intermediate shafts as possible, which of course requires that large pulleys shall drive proportionally smaller pulleys than if the rate of the reduction of speed were more moderate. On the other hand, the experience of many founders proves that by moderately attaining the speed by the use of a greater number of intermediate belt pulleys, repairs of any importance are not incurred for months and even years. The great evil of too rapidly raising the speed is the aptitude of the belt to slip upon the drums; for when slipping occurs, especially among the slower parts of the motion, the belt is subjected to sudden and violent strains, caused by its unequal hold upon the rim of the drum. The usual remedy for this state of things is to apply rosin and pitch to the acting surface of the belt to give it a hold. But the best plan is to employ spur gear in the slower parts of the motion, and broad belts and pulleys of conveniently large diameters for the rest.

A properly constructed fan will work for many years without any perceptible wear, but in working they frequently make an unpleasant noise, especially when driven at high speeds.

The position of the fan in its case is preferably eccentric. The

continually-increasing winding passage between the tips of the vanes and the chest serves to receive the air from every point of the circumference of the fan, and produces a general accumulating stream of air to the exit pipe. The particles of air having passed the inlet opening, and entering on the heel of the vane, would retain the same circular path, were it not for the centrifugal force of the air, due to its weight and velocity, impelling them forward toward the tips of the vanes; and this continued action is going on, particle following particle, till they are ultimately thrown against the fan chest, and are impelled forward to the exit pipe. It is by this centrifugal action that the air becomes impelled and accumulated into one general stream. But there is a certain velocity of the tips of the vanes which best suits this action.

The pressure of the air in the pipe and chest, by the continuous rapid motion of the vanes, may be measured by a water or mercurial gauge attached to the blast chest.

It has been found that the greatest results are obtained when the theoretical velocity and the velocity of the tips of the vanes are nearly equal.

Water is 827 times heavier than air, and mercury is 13·5 times heavier than water, or 11,164 times heavier than air; so that a column of mercury 1 inch in height would balance a column of air 11,164 inches, or 930·3 feet in height. A column of mercury of 30 inches is equal to a pressure of 15 lbs. on a square inch; a column of mercury of 1 inch gives a pressure of ½ lb. per square inch. A column of mercury one-eighth of an inch in height gives a pressure of 1 ounce per square inch. Hence the height in inches of a column of mercury, equivalent to any given pressure or density, is found by dividing the density in ounces per square inch by 8.

The centrifugal force of air coincides with the results of the laws of falling bodies, that is, when the velocity is the same as the velocity which a body will acquire in falling the height of a homogeneous column of air equivalent to any given density. Thus, taking the velocity, as obtained by the law of falling bodies, we find the centrifugal force or density of the air.

The velocity of the air and the diameter of the fan being given, the rule to find the centrifugal force is:—Divide the velocity in

feet per second by 4·01, and again divide the square of the quotient by the diameter of the fan in feet. This last quotient multiplied by 1·209, the weight in ounces of a cubic foot of air at 60° Fahr., is equal to the centrifugal force in ounces per square foot, which, divided by 144, is equal to the density of the air in ounces per square inch.

To ascertain the *theoretical velocity*, the mouth of the discharge is closed, the velocity of the fan merely keeping the air at a certain pressure per square inch, when it is found that the tips of the vanes must move with nine-tenths of the velocity a body would acquire in falling the height of a homogeneous column of air equivalent to the density.

It is found that nine-tenths of the theoretical velocity is the most effective speed, when the fan is not discharging air, but that the same proportion holds good also when the outlet pipe is open; that is, that the maximum effect of the fan is when the vanes move with a velocity ranging from the theoretical velocity due to the density of the air, to nine-tenths of that velocity, the greatest quantity of air being discharged by the fan with the least expenditure of power. By making the top of the opening level with the tips of the vanes, the column of air has only a slight reaction on the vanes.

The degree of eccentricity of the fan in the casing that has been found to work well, is one-tenth of the diameter of the fan; that is, the space between the fan and the casing should increase from three-eighths of an inch at the top of the outlet to the delivery pipe, to one-tenth of the diameter of the fan at the point perpendicularly under the centre.

The main pipe from the casing may be not less than 1¼ times the area of the delivery pipe when under 100 feet in length; for greater lengths it should be 1½ times the area of the delivery pipe.

From experiments made to establish the best proportions o inlet openings in the sides of the fan chest, and the suitable corresponding lengths of vanes, it was found that by impeding the free admission of air to the vanes a loss of power was occasioned. It was also found that the longer vane has a preponderating advantage over the shorter vane, in condensing air to the greatest density with the least proportion of power.

It will, therefore, be seen that the three most essential points in the economy of the fan, namely, the *quantity* and *density* of the air, and the expenditure of *power*, depend on the proportion of the length and width of the vanes, and the diameter of the inlet openings.

The width of the vanes, and their length, should be one-fourth of the diameter of the fan, and that the diameter of the inlet opening in the sides of the fan casing should be one-half of the fan. The Table VIII. gives the approximate dimensions of fans for obtaining the best results, varying from 3 to 6 feet in diameter. The first six are the proportions for densities ranging from 3 to 6 ounces per square inch, the second six are for higher densities:—

TABLE VIII.—DIMENSIONS OF COMMON FANS.

Diameter of Fan.		Width of Vane.		Length of Vane.		Diameter of Inlet Opening.	
ft.	in.	ft.	in.	ft.	in.	ft.	in.
3	0	0	9	0	9	1	6
3	6	0	10½	0	10½	1	9
4	0	1	0	1	0	2	0
4	6	1	1½	1	1½	2	3
5	0	1	3	1	3	2	6
6	0	1	6	1	6	3	0
3	0	0	7	1	0	1	0
3	6	0	8½	1	1½	1	3
4	0	0	9½	1	3½	1	6
4	6	0	10½	1	4½	1	9
5	0	1	0	1	6	2	0
6	0	1	2	1	10	2	4

Table IX. gives particulars of some experiments made with a large fan used to blow the cupolas, &c., at the London Works, Birmingham. Although in the early experiments only 36 to 50 per cent. of useful effect was obtained, eventually as much as 75·16 was obtained. No allowance was made for obstruction in the fire, but the area of the tuyeres was taken, having taper pipes leading to them, and the velocity of the air, multiplied by the pressure, was taken to represent useful effect in horse-power.

A considerable difference in the amount of useful effect was sometimes produced by the same power, but this arose either from a difference in the area of opening, or in the pressure. When the pressure was great the result was generally affected, it being easier to get a moderate pressure with a fan than a high one. A 7-inch

TABLE IX.—EXPERIMENTS WITH COMMON FANS.

No. and Size of Blades.	Revolutions of Engine per Minute.	Revolutions of Fan per Minute.	Velocity of Tips of Blades.	Theoretical Velocity of the Air in Feet per Minute.	Pressure of Blast in Inches of Water.	Diameter of Fan Tips of Blades.	Area of One Blade in Square Inches.	Area of Discharge.	Total Power of Engines.	Friction, &c.	Power Absorbed by Fan and Counter Shaft.	Weight and Velocity of Air Delivered, H.P.	Percentage Useful Effect.
						ft. in.							
6 Blades, with centre plate, 16 × 8	25	712·5	12312	11358	$8\frac{5}{8}$	5 6	128	128	64·31	26·7	37·6	13·6	36·1
	..	..	..	9954	$6\frac{5}{8}$	..	..	354	74·5	..	47·7	25·8	54
4 Blades, 16 × 12	20	514·28	8818·9	7740	4	5 $5\frac{1}{4}$	192	194	41·	22·38	18·56	6·9	37·17
	$22\frac{1}{2}$	578·57	9921·2	8646	5	..	..	..	48·4	25·66	22·78	9·63	42·26
4 Blades, 16 × 8	25	712·5	12312	9678	$6\frac{1}{4}$	5 6	128	354	63·5	28·7	34·8	23·37	67·1
	..	..	..	10938	8	..	..	128	51·6	..	22·9	12·28	53·4
4 Blades, $18\frac{1}{2}$ × 12	..	..	11192	10235	7	5 0	219	220	51·2	26·	25·28	17·22	68·0
	..	..	..	10928	8	..	..	157	47·5	..	27·5	15·00	70·1
	..	..	..	9858	$6\frac{1}{2}$	..	..	354	55·8	22·1	33·73	24·78	73·4
4 Blades, $18\frac{1}{2}$ × 10	..	..	..	10500	$7\frac{3}{8}$	5 0	182·5	182	51·8	27·6	24·2	15·25	63·0
	..	..	..	9474	6	..	..	354	58·2	..	30·7	21·99	71·6
4 Blades, 16 × 12	..	..	..	10235	7	..	192	194	51·2	27·33	24·	15·18	63·5
	..	..	..	9377	$5\frac{7}{8}$	..	..	354	56·1	..	28·76	21·31	74·1
4 Blades, 17 × 12	..	..	..	10235	7	..	204	204	51·	27·7	23·25	15·97	68·68
	..	..	..	9474	6	..	..	194	57·	..	29·1	21·9	74·2
4 Blades, 16 × 11	..	..	..	10140	$6\frac{7}{8}$	..	176	180	50·	28·34	24·5	13·7	63·8
	..	..	..	9173	$5\frac{5}{8}$	..	..	354	54·7	..	26·41	19·97	75·16

column of water is considered ample for cupolas. In all cases indicator figures were taken in order to arrive at the power employed, and figures were also taken separately without the fan, in order to get at the friction of the engine and shafting.

The fan case was an arithmetical spiral, so that the blades delivered the air regularly, and the following rules were deduced from the experiments:—

That the fan case should be an arithmetical spiral to the extent of the depth of the blade at least.

The diameter of the tips of the blades should be about double the diameter of the hole in the centre; the width to be about two-thirds of the radius of the tips of the blades. The velocity of the tips of the blades should be rather more than the velocity due to the air at the pressure required, say one-eighth more velocity.

In some cases, two fans mounted on one shaft would be more useful than one wide one, as in such an arrangement twice the area of inlet opening is obtained as compared with a single wide fan; such an arrangement may be adopted where occasionally half the full quantity of air is required, as one of them may be put out of gear, thus saving power.

If it is considered necessary to provide means to vary the area of admission to the delivery pipe, this can be effected by arranging a segmental slide to the circular fan casing, as shown in Figs. 1 and 2, Plate XXIII., when by means of a ratchet and pawl the depth of the opening into the delivery pipe can be varied, and the power required to drive the fan be diminished. The air-shaft may be built of brickwork, in which case the inside should be cylindrical in section, and the surface covered with a smooth coat of plaster or cement, but iron pipes with well-made joints are by far the best.

The inlet opening on the casting of the fan should be provided with a bell-shaped lip or taper flange all round, extending several inches outwards; this improvement adds to the useful effect of the fan, and tends to reduce noise.

Fans are less expensive in first cost and repairs, for a given duty, than blowing engines; but when high pressures are required, they take somewhat more power to drive them. In other words, the fan is not an economical machine, in the sense of useful effect for a certain power; and its useful effect or "duty" decreases

rapidly as the speed is increased for the purpose of increasing the pressure of blast. The power for driving a fan or fans is generally best given by a small high-pressure engine, communicated by a belt.

The engine should run at a quick speed, and be provided with a tolerably heavy fly-wheel, to prevent its running away in case of any accident to the driving belt or fan. In order to get an increase of speed from the engine, the fly-wheel may be driven by a sun-and-planet motion instead of a crank; this will give two revolutions of the fly-wheel shaft for each double stroke of the piston, and then with a large pulley on the fly-wheel shaft, and a small one on the fan axle, a high speed can be obtained. But for many reasons it is inadvisable to use the sun-and-planet motion, if it can possibly be avoided. If a large volume of blast is required at a moderate speed, this can best be obtained by employing a fan of large diameter, driven at a moderate speed; but where a high pressure, or great velocity, of blast is desired, it is necessary to drive the fan rapidly.

It is not advisable to construct a fan larger than 8 feet in diameter, and for most ordinary purposes one of about 5 feet diameter across the vanes is to be preferred.

A silent fan can only be obtained by having vanes which do not fill the casing, having the vanes placed eccentrically in the casing, and forming the casing in a true spiral.

Provide ample apertures for the entrance and exit of the air, avoid sharp turns or projections in the casings, and in designing and fitting up the fan all the moving parts must be securely fixed in position, so that they will be able to withstand the great centrifugal force brought on them when driven at a high speed, as, if any part becomes detached during working, great damage and probable loss of life would ensue.

Fans, especially when large and driven at a high speed, should be walled in all round, and every precaution adopted to avoid loss of life, in case of any accident occurring to the fan whilst it is in motion. The castings for fans should be made massive, as tending to reduce the vibration felt when fans are worked at a high speed.

NOTES ON THE CONSTRUCTION OF FANS.

Good Proportions.

Inlet $= \frac{1}{2}$ diameter of fan.
Blades $= \frac{1}{4}$ diameter of fan each way.
Outlet $=$ area of blades.

The area of tuyeres is best when about

$$= \text{to } \frac{\text{area of blades}}{\text{density of blast, ozs. per sq. in.}},$$

and it should not exceed twice this area.

TABLE X.—VELOCITY OF CIRCUMFERENCE FOR DIFFERENT DENSITIES.

Velocity of Circumference. Feet per Second.	Density of Blast. Ozs. per Inch.
170	3
180	4
195	5
205	6
215	7

250 to 300 feet per second is a proper speed for cupolas.

To find the Horse-power required for a Fan.

D = density of blast in ounces per inch.
A = area of discharge at tuyeres in square inches.
V = velocity of circumference in feet per second.

$$\frac{\frac{V^2}{1000} \times D \times A}{963} = \text{horse-power required.}$$

To find the Density to be attained with a given Fan.

d = diameter of fan in feet.

$$\frac{\left(\frac{V}{4}\right)^2}{120 \times d} = \text{density of blast in ounces per inch.}$$

TABLE XI.

Velocity of Circumference. Feet per Second.	Area of Nozzles.	Density of Blast. Ozs. per Inch.
150	Twice area of blades	1
”	Equal ”	2
”	½ ”	3
170	⅓ ”	4
200	¼ ”	4
”	⅓ ”	6
220	¼ ”	6

To find the quantity of Air, of a given Density, delivered by a Fan.

TABLE XII.—Total Area Nozzles in Square Feet × Velocity in Feet per Minute, corresponding to Density (see Table) = Air delivered in Cubic Feet per Minute.

Density. Ozs. per Square Inch.	Velocity. Feet per Minute.	Density. Lbs. per Square Inch.	Velocity. Feet per Minute.
1	5,000	1	20,000
2	7,000	1½	24,500
3	8,600	2	28,300
4	10,000	2½	31,600
5	11,000	3	34,640
6	12,250	4	40,000
7	13,200	6	49,000
8	14,150	8	56,600
9	15,000	10	63,200
10	15,800	12	69,280
11	16,500	15	78,000
12	17,300	20	89,400

Another variety of machine for blowing cupolas is that known as a "pressure blower," which produces a blast having a positive force and distinguished from a fan, which does not produce a force blast. In this respect, a blower is analogous to cylinders used for producing blast. In either case, the air forced must find an outlet, or the machine stops. But a fan can run with the outlet obstructed or entirely closed, without being in the least impeded. In a pressure blower, in which the air is forced forward by a revolving vane or piston, the whole of the power applied, except the amount absorbed by the friction of the moving parts of the machine, is utilized in producing pressure; and should the outlet from the blower be throttled, the pressure of the blast will continue to rise until the limit of the driving power is reached, when the machine must stop. With a fan, however, the case is different; it must be run at a very high velocity to impart a sufficient momentum to air, a substance possessing only a very slight specific gravity; thus there is very considerable loss of power from the friction of the bearings, the journals of which run at such extreme speed, as well as from the power absorbed in continually changing the direction of the belts, which take short turns round very small pulleys, and

but a portion of the air thus acted upon is really forced forward. Should the outlet from the fan be partially throttled, there will be but a very slight increase of pressure in the blast while the fan continues to run at the same speed; and if the outlet be entirely closed, the fan will still continue running, absorbing much power, but producing no practical effect.

Gwynne and Co.'s Blower is shown in Figs. 1 and 2, Plate XXV. A is the case, B the spindle, C the bed-plate, D suction pipe, E discharge pipe, G slides of piston.

This blower is composed of an outer casing or cylinder A, fitted with top and bottom plates, one of which plates is constructed with a stuffing box and gland, through which passes the spindle B, on which is fixed an inner cylinder. This inner cylinder is slotted through the centre, which slot is fitted with two sliding plates or pistons G, made air-tight to the slots, and working air-tight against the inner periphery of the outer cylinder.

The two cylinders, as shown in the figures, are set eccentrically to each other, so that the bottom of the inner cylinder touches the bottom of the outer cylinder.

When the spindle B is set in motion the slides continue to pass in and out, and thereby take up the air which enters through the pipe D, and is expelled through the pipe E.

The machine is fixed to a firm cast-iron bed-plate, so as to be perfectly portable; and it requires little or no foundation; it has not, we believe, been very extensively applied to foundry purposes.

The best known blower at present is Roots', an American invention, but used largely in England, and made here by Thwaites and Carbutt, of Bradford.

Roots' Blower, as arranged for foundry work, is shown in Figs. 4 and 5, Plate XXV. It has rotary pistons covered with wood lags, by which construction the pistons can be made lighter than cast-iron pistons, and thus take less power, run more quietly, and at twice the speed of the iron pistons. The thickness of a sheet of paper is the only clearance that is allowed, and, in order still further to reduce the clearance, a frictionless composition is applied with a brush evenly over the surface of the hollows of the rotary pistons, until every portion of the pistons is shown to be in contact.

This composition is made as follows:—

Tallow	6 parts
Plaster of Paris	6 „
Beeswax	3 „
Black-lead	1 „

thoroughly mixed together and melted, and allowed to cool sufficiently before application.

The composition is of the consistency of ordinary paint, and also answers the purpose of preserving the wood. The wood used is the finest selected deal, free from knots, thoroughly seasoned and dried for three years. The lags are held upon malleable cast crossheads with bolts, which, for security, have the bolt ends riveted over the nuts. At the joints of the wood lags is inserted an iron tongue, which runs the whole length of the joints. The end plates are planed, and are provided with bosses, which are bored and fitted with hard gun-metal bushes, forming the bearings for the steel shafts. These gun-metal bearings are long, with considerable area of wearing surface, and can be easily replaced when worn out. The side plates of the casing are half cylinders, cast separately, planed on the flanges, bolted to form a circle, and then bored out as true as a steam-engine cylinder; the side plates and end plates are connected together with fitted bolts. The outlet branch is fixed in most cases at the bottom, and a perforated box-cover is fixed at the top to admit the air, and to prevent anything else from entering the machine. At each end, outside the casing of the blower, is fixed a pair of accurately-pitched spur-wheels for gearing the two pistons together, which are covered in with iron boxes. Upon the iron box is fixed a cover plate, provided with gun-metal bushed bearings for the shafts, and outside of these covers are fixed the driving pulleys on one end of one shaft and on the opposite end of the other shaft, a crossed and open belt from a counter-shaft being used for driving; and outside the driving pulleys are fixed additional bearings to take the pull off the driving belts. All portions of these are made in duplicate, and the wood-covered rotary pistons are correctly shaped to templates by a wood-planing machine. The original method of hand-shaping the revolvers, which was at first tried, could not be depended upon to produce the rotary pistons quickly and with sufficient accuracy. It appears that iron pistons,

which frequently replace the wooden pistons in these blowers, are decidedly to be preferred if the blower is to be placed in a situation at all liable to dampness.

The following Table furnishes some interesting particulars as to the dimensions, work, dimensions of discharge pipes, and other details respecting Roots' blowers:—

TABLE XIII.—PARTICULARS OF ROOTS' ROTARY BLOWERS.

Number of Blower.	Melting Iron.			Approximate Horse-power.	Volumes of Blast in Cubic Feet delivered per Minute.	General Dimensions.									Approximate Weights.
	Number of Revolutions per Minute.	Tons of Metal per Hour.	Adapted to Cupola Inside Lining.			Diameter of Pulleys.	Breadth of Pulleys.	Diameter of Delivery Orifice.	External Dimensions.						
									Length.		Breadth.		Height.		
			in.			in.	in.	in.	ft.	in.	ft.	in.	ft.	in.	cwts.
No. 2 A.	330	2½	24 to 30	2	1650	14	5	8	3	10	3	0	2	6	8½
No. 2	400	3	24 „ 30	2	2000	12	4	8	4	8	3	0	2	6	9½
No. 3	350	4½	30 „ 36	4	3000	14	5	10	5	8	3	0	2	8	12
No. 4	325	8	36 „ 48	6	4550	16	6	12	6	8	4	0	3	4	18
No. 5	320	12	48 „ 60	8	6400	18	7	14	7	10	4	0	3	6	23
No. 6	310	16	..	11	8680	20	9	18	8	0	5	0	4	0	30

It would appear that this machine, when fitted with wood pistons, is rather liable to be affected by variations in temperature, a matter which must be attended to in fixing the machine.

A blower of very ingenious construction is that invented by John G. Baker, of Philadelphia, and shown in section Fig. 3, Plate XXV. It is already largely employed, both in England and in America, and promises to become a standard machine for foundry use. It consists, as will be seen from the figure, of three drums, the upper drum being furnished with two blades or vanes passing alternately through wide openings made to receive them in the two lower drums. This blower is made entirely of iron, the cylindrical portion or case bored out and faced on the ends, the heads of the machine, or ends upon which the bearings are bolted, being also faced off true. The case is secured at the ends by bolts, and when in exact position the ends are doweled, so that when the case is removed it can be returned to position without delay. The base is a solid casting faced on its upper side, and bolted firmly to the ends

of the machine; the drums are each cast in one piece, turned truly and balanced to ensure closeness, and at the same time to render them steady when running; the slots in the two lower drums extend throughout their entire length, and are made considerably wider than is needed for the passage of the wings, in order to ensure freedom in action, and prevent any danger of the wings striking against them when entering or leaving; the wings of the central drum are faced off and bolted on firmly, they are cast in the requisite form to ensure the greatest strength in proportion to their weight. As with other machines of this class the bearings in general are made large, to secure extended bearing surface, and give the journals such a degree of strength as to prevent them springing, and to overcome rapid wear. To find the amount of power to be used with one of these machines, the following formula will be found useful, the quotient will be the actual horse-power, less the friction of the blower:—

2 = cubic feet of air delivered per minute.
P = pressure in ounces per square inch at blower.
H.P. = indicated horse-power required.

$$\text{H.P.} = \frac{2\,\text{P} \times \cdot 003}{11}.$$

The Table following relates to Baker's Blowers, the sizes being those made by the Saville Street Foundry Company, Sheffield:—

TABLE XIV.—PARTICULARS OF BAKER'S BLOWERS.

Number of Blower.	Cubic Feet Displaced per Revolution.	Number of Revolutions per Minute.	Size of Cupola.	Iron Melted per Hour.	Diameter of Blast Pipe.
			inches.	tons.	inches.
3	3	110	18 to 22	$\frac{3}{4}$	$6\frac{1}{4}$
"	"	180	"	$1\frac{1}{4}$	"
6	6	105	22 to 27	$1\frac{1}{4}$	8
"	"	150	"	2	"
9	9	100	27 to 30	2	$8\frac{1}{2}$
"	"	130	"	$2\frac{1}{2}$	"
13	13	95	30 to 34	$2\frac{1}{2}$	$9\frac{1}{2}$
"	"	120	"	$3\frac{1}{4}$	"
17	17	85	34 to 40	$3\frac{1}{4}$	$11\frac{1}{2}$
"	"	115	"	5	"
25	25	75	40 to 48	5	14
"	"	110	"	8	"
30	30	70	48 to 52	8	15
"	"	105	"	10	"
60	60	60	52 to 84	10	24
"	"	100	"	20	"

Blowers should be set on good solid stone foundations, to which they should be held by proper bolts, and care should be taken to set them level lengthwise. Too much stress cannot be laid upon the necessity of providing iron piping for the air-conducting pipes, and seeing that these, with the shut-off valves and connections, are *perfectly tight.* An escape valve may be fixed with advantage upon the air-pipes, to relieve the blower from too great an increase of pressure of air, caused by the closing of the shut-off valves while the machine is in operation.

It is to be regretted that no more definite and independent information is to be obtained with regard to the superiority and relative advantages of the various pressure blowers in use, and of the comparative results obtained by such machines as applied to the foundry cupola, than that issued by their respective manufacturers. The subject has not yet received the attention it deserves at the hands of the ironfounder in this country, nor have the results been so carefully worked out here as in the United States of America, where the conditions of working are somewhat different; and it must be inferred from their tardy adoption that the advantages offered have not been clearly understood or appreciated by the users here, many of whom have a strong preference for the fan.

There are, however, certain well-known advantages in their use as against the fan, which are more than sufficient to cover the increased cost of their adoption, and these will be now considered. The first great difference lies in the fact that the pressure blower is a positive or force blast, measuring accurately the amount of air delivered per revolution; the fan is not, nor can it be made to do so, whatever its construction. How far this is beneficial will appear farther on. The fan is able to produce a pressure from the fact that air possesses a slight specific gravity, and by setting in motion arms or beaters at a high speed, sufficient centrifugal force is produced to repel the particles of air outwards or towards the delivery by beating it. By rapidly increasing this centrifugal action its density and consequent pressure may be effected up to a certain point.

In the blower, however, the quantity of air forced forward per revolution is practically the same, whether making 100 or 200 revolutions per minute, and does not in any degree depend upon

centrifugal action or upon the specific gravity of the air to give a definite displacement, and this commends the blower as a source of economy in promoting the combustion of the fuel in the furnace, and in the power necessary to drive it, as the difference in speed alone in the two machines varies from 100 to 5000 revolutions per minute.

In order, therefore, to maintain a pressure such as is ordinarily required for smelting iron, the fan must sometimes run at a speed dangerously near the bursting strain of the materials of which it is composed, whilst there is a limit to the pressure which can be attained by this centrifugal force, and when that limit is reached, no more air will be forced forward, however the speed may be increased, thus absorbing power uselessly. This fact admitted, it follows that the effectiveness of a fan to deliver a given quantity of air, is proportionately impaired by the degrees of resistance which are brought into operation during the melting process; and this argues that there is a constant uncertainty as to the amount of air entering the cupola, whilst it is equally clear that under such conditions the same, nay more, air is required in the interior of the furnace to produce an economical yield of iron per lb. of fuel burnt. As the melting proceeds the tuyeres become foul from the accumulation of slag and cinders in the interior to such an extent, that the melting ceases, and the iron is rapidly decarbonized, loses its fluidity, and is rapidly chilled, so that the castings are bad from being run short, too hard or unworkable with the tools which follow, producing much waste.

We have testimony from many ironfounders on this important point; in many instances inferior brands of iron are used with the blower blast for precisely the same class of work as formerly required the most expensive pigs when the fan was used, and with better results.

We cannot reduce iron without fuel, but there is a necessary quantity, and the proportion of air is as definitely fixed for its complete combustion; any excess of either is simply so much extra cost put upon the cost of the castings produced.

We know also that there is a certain degree of heat necessary to melt the largest amount of iron in a given time with the least amount of fuel, but it is possible to consume any quantity of coke without melting a single pound of iron, if the temperature is not sufficiently elevated by a judicious admission of the necessary

oxygen, to combine with the carbon of the fuel; so that a machine delivering a fixed quantity of air in a given time is as necessary as the knowledge of how much coke is required per ton of iron put into the cupola. But as combustion can only proceed at a certain rate, it is equally important that too much air is not forced therein, otherwise the temperature of the furnace gases is lowered.

When the proper amount of air is supplied the combustion is perfect, and the highest rate of melting attained; but then we must remember that as the carbon seizes upon the oxygen of the air and converts it into carbonic acid on its entrance at the tuyeres, so this compound is rapidly reconverted into carbonic oxide as it ascends through the charge, from the liberation of the hydro-carbons and other gaseous elements of the fuel; and that in order to secure the highest temperature and efficiency we must be enabled to inject continuously a given quantity of this oxygen to prevent the formation of carbonic oxide, and this can only be done by some machine which delivers positively under all conditions of the furnace a fixed quantity.

We have said enough to prove the importance of fixed quantities of fuel, air, and iron in the economical production of castings; but the diagram, Fig. 1, Plate XIV., illustrates forcibly what actually takes place in the cupola, showing the operation of the blast in actual work, using a Baker's blower and comparing the pressure with those of a fan.

The irregular, crooked and dotted lines show five different heats taken from a 37-inch cupola inside the lining, measuring at its largest, or at 20 inches above the tuyeres. Blast given with a No. 17-feet Baker blower, running 93 revolutions per minute, blast pipes cast iron, and perfectly air-tight.

The horizontal lines on the diagram show pressure in ounces per square inch, and the vertical lines time, divided into spaces of five minutes each. On examination of the diagram it will be observed that when the blast is first put on, the pressure will be somewhere near ten ounces, slightly diminishing the first fifteen minutes, until the iron commences to melt, then rapidly increasing in pressure until the highest limit is obtained, which is in about an hour and a quarter after the blast is put on. The fuel used was the best anthracite lump coal, and the iron was two-thirds pig and one-third sprues, small gates, fine scrap, &c., at last of the heat.

The average amount of power, number of lbs. of iron melted per lbs. of coal used, and iron melted per lb. of coal, are given in the accompanying Table:—

TABLE XV.—WORK DONE BY 37-INCH CUPOLA AND BAKER'S BLOWER.

Reference letter on Diagram.	Time in Minutes.	Average Horse-power during heat.	No. lbs. Iron Melted.	Pounds of Coal used.	Iron Melted per Hour.	Iron Melted per Minute.	Lbs. Iron Melted per lbs. Coal used.
A	92	7·45	12,000	1,500	9,729	162	8,000
B	99	7·40	12,000	1,450	8,780	146	8,275
C	100	7·55	12,100	1,550	9,075	152	7,800
D	101	7·60	12,550	1,550	9,181	153	8,032
E	111	7·50	13,873	1,650	8,950	149	8,403
Average	101	7·50	12,504	1,540	9,143	152	8,102

A careful study of the diagram reveals several important facts to which we would call attention:—

1st. The ever-varying conditions of the furnace as regards the pressure of blast to produce the results, shown by the unsteadiness of the lines.

2nd. That under ordinary circumstances, such a resistance to the passage of the air through the charge in the furnace is imposed, as to cause a considerable increase in the pressure ot the blast, and that if the machine is not capable of answering such conditions, there must be a corresponding loss, both in fuel and the quality and quantity of castings turned out in a given time.

3rd. Seeing that the highest pressure required is from 20 to 24 oz. per square inch, it is impolitic to employ a fan whose highest duty is 16 oz., not that pressure is a *sine quâ non* for smelting in the cupola, but that in order to introduce the necessary amount of oxygen per pound of fuel the internal resistances reach such a point as to cause a corresponding increase in the density of the air.

As a mere question of mechanical arrangement, simplicity, and economy of power, no thoughtful mind can doubt for a moment the advantage of running at a low speed with a positive displacement per revolution, and knowing exactly what air is being delivered against the excessively high speeds, with the multiplicity of belts, pulleys, shafts, bearings, and all the paraphernalia incident to the successful working of a fan.

CHAPTER XI.

PATTERNS.

In order to mould a quantity of melted metal into any desired form two things are necessary, a model or pattern of the required form, and a substance of sufficient susceptibility and adhesiveness to receive accurately and to retain impressions of that pattern made upon it, against the violence of the liquid metal when run into the space which is thereby formed. The making of patterns is a trade in itself, involving in its pursuit the manipulative knowledge of the turner and joiner, and into the bench details of this trade it is not our purpose to enter; but those desirous of studying these details would do well to read the capital little treatise of Joshua Rose.

Wood is almost universally employed as a material for patterns, pine or deal and mahogany being the kinds chiefly used. Of these, pine is by far the most useful, in consequence of its uniformity of substance, freedom from knots, clean and easy working, and abundance. Yellow or white pine is particularly good for long and nearly flat work; it does not warp much, is not likely to split, and is light to handle. It has a fine grain, and is left smooth after the tool. It should not be roughly used, however; being soft, it is easily injured by a blow or a fall, and will be injured if placed in situations where it is likely to be subjected to such contingencies.

Canadian red pine is harder than the above, and may well be substituted for it, if it is chosen free from large knots, and not too much impregnated with turpentine.

White American fir or spruce is best for large wheel patterns, especially when they have to be built up and glued together before being turned in the lathe. It should be cut into thin slabs, and slowly seasoned, when it will not be found to split. When the slabs are glued together, the grain of each slab should be placed diagonally to that next it. This is a harder wood than yellow pine or yellow Canadian.

We entirely agree with Rose, the American machinist, when he states that, "Care taken in its selection will be amply repaid in the workshop. When it is straight-grained, the marks left by the saw will show an even roughness throughout the whole length of the plank; and the rougher the appearance, the softer the plank. That which is sawn comparatively smooth will be found hard and troublesome to work. If the plank has an uneven appearance, that is to say, if it is rough in some parts and smooth in others, the grain is crooked. Such timber is known to the trade as catfaced. In planing it the grain tears up, and a nice smooth surface cannot be obtained."

Mahogany shrinks but little in drying, and twists and warps less than any other wood, on which accounts it is largely used in pattern making. Spanish mahogany is considered the best, and Honduras next. African is inferior, as it alters its shape in drying.

Mahogany does excellently for small patterns, but its expense limits its application to the construction of these. It can be cut very clean, and its superior density and closeness of grain render it well fitted for nice patterns, such as of bushes for journals, small pinions, the teeth of wheels below 1 inch in pitch, and in every case of a similar nature in which the fibres of the wood may be presented endwise to the surface; whereas in working fir in this manner for minute purposes, it is apt to be broken away at the edges.

Cherry-tree wood is good for patterns when well seasoned. It is used in Germany for making patterns for fine castings for cabinet work. It is a hard, close-grained wood, that of the black-heart cherry being considered the best.

Beech has an excellent uniform texture, and is much used for turnery purposes, keys and cogs of machinery, and for patterns.

Teak is a light porous wood, easily worked, but which is also strong and durable. It is soon seasoned, and being oily does not injure iron. The timber contains a quantity of silicious matter, which is very destructive to edged tools. The best teak comes from Moulmein.

The choice of wood for pattern making is governed by the following considerations:—It should be free from knots, close and straight grained, with the annual rings not too strongly developed,

and not too hard to be easily and neatly worked to the desired form. There are several woods which, although admirably adapted for pattern making in these respects, are still, from their tendency to split, only to be used with great caution, notably teak and greenheart. Patterns made of sycamore, maple, box, oak, and elm generally require to be varnished or painted before being placed in sand; otherwise, however dry and smooth they may be, they may not draw cleanly from the mould.

We have given here but a short *résumé* of the leading characteristics of the different kinds of wood used by pattern makers, but if fuller particulars should be required on this topic, the reader is recommended to consult vol. i. of Holtzapffel's 'Turning and Mechanical Manipulation.' That work contains a very complete list of British and foreign woods, although comparatively few of these are used in pattern making.

A more recent work, 'Tredgold's Carpentry by J. T. Hurst,' contains information about timber, which will also be found very serviceable.

No large foundry should be without sufficient stock of seasoned wood for patterns, nor without a properly constructed drying room for desiccating such timber.

In a foundry nothing is more wasteful than the employment of half-seasoned wood when the patterns are to be of any permanent value. They warp, split, and change form, and though still capable of being moulded from, parts intended when cast to go together with a minimum of fitting, are found to require a great deal more than need be, and sometimes cannot be got together at all without thick chipping strips being tacked on to the meeting faces of the junctions in the patterns, or perhaps even packing pieces of iron in the work itself. The stock of fully-seasoned pattern wood should not be left at the mercy of the pattern makers, to cut it up how and when they like, at their own discretion. Every joiner prefers to work dry wood, which works so much more easily than what is unseasoned. There is a desire to employ always a finely-seasoned wood, whether necessary or not, and for many large patterns it is not so. When the drawings come from the drawing office, the foreman should direct the pattern maker as to the timber to be employed, and check the quantity taken off by each man.

Timber is seasoned by being exposed freely to the air in a dry place, protected if possible from the sunshine and high winds. The timber is stacked so as to allow of the free circulation oi air amongst it, and should be slightly raised from the ground on stone or iron bearers. If the timber is allowed to remain in water for a fortnight, the subsequent seasoning and drying is more rapid.

Time is the best seasoner of timber; but space and other economical considerations usually cause founders to abridge the time by artificial seasoning. This is often done by piling the sawn planks into racks, provided over the boilers of the engine which drives the machinery of engineering works. In large works it is much safer to have a proper oven or desiccating kiln, specially made for the timber, and heated by the waste heat from some boiler or fire. The heat must not be great, and a steady, gentle current of dry air through is essential. When the wood is quite dry, it is best stacked in racks horizontally in the open air, but under cover from rain.

Large patterns when quite done with should be taken to pieces, and the more useful portions of timber they contain be cleaned and stacked for use again. Those patterns which are to be preserved for future use should be stored in an orderly manner, exposed to the open air, but roofed over to keep them dry.

Wheel patterns occupy a great deal of room, for they must be stacked upon the flat over each other in piles, only bearing upon each other at the eyes of the wheels. They should be placed on the ground floor, which should be boarded; and in a large mill-wright establishment, where spur and bevel wheel patterns of 10 or 15 feet diameter are not uncommon, a light overhead traveller would with advantage be so arranged as to pick out any pattern from any part of the room.

The upper floor answers well for all other classes of patterns. The iron and the brass or gun-metal work patterns are usually best classified quite distinctly. But in marine engine and locomotive work it will always be best to place the whole of the patterns for the parts of each engine together, whether they be for iron or for brass. Drawings to full size on boards, templates, gauges, and the like for such work, are best also deposited adjacent to and in order with the patterns.

Some woods, such as oak for instance, have such powerful capillary attraction that when placed in contact with the moulding sand they rapidly imbibe the moisture from it, and adhere so firmly to the face of the mould, that they cannot be withdrawn cleanly and smoothly from it.

Deal and red cedar are more free from this objection, as their grain has much less attraction for moisture, and thus allow the patterns to draw with ease from the sand.

Some of the hard woods which are occasionally employed, such as ebony and box, have surfaces almost as hard and unabsorbent as a metal. But there are also several hard, close-grained woods, which cannot be made to draw clean from the sand—poplar, sycamore, and pear tree, for example. This is unfortunate, as these woods are, in other respects, pleasant to work on. If the surfaces of the pattern made from these woods can be left quite fresh from the cut of a keen-edged tool, the difficulty is reduced, but if they have been finished with a file or glass-paper, the grain will be so fringed up, that it will be impossible to obtain a clean green-sand mould from the pattern.

As a precaution against these defects in the wood, and also as a preservative for the patterns, they are usually coated with varnish, or oil paint, &c. Thus their capillary attraction is lessened, and their surfaces made smooth and glossy. There is nothing better for this purpose than a moderately hard drying oil paint, black-leaded over when dry. One mode of coating patterns is to paint them with a thin coat of oil paint, consisting of red-lead and acetate or sugar of lead. Allow this to dry in a warm room, then carefully rub over with sand-paper, and finish with powdered chalk; or a thin coat of a less rapidly setting oil paint may be applied, and the surface finished with pumice-stone, and very fine glass-paper. Rub well with a soft cloth, then put on a coat of black-lead mixed with beer, applied with a hard brush.

When only one or two castings are required from a pattern, especially if it should be of an ornamental and delicate character, this coating of black-lead and beer may be applied directly to the naked wood of the pattern. This plan answers very well where the wooden pattern is to be employed simply for the production of a metallic pattern. But it is certainly desirable that patterns

which have to be used several times should be painted in oil, more especially when they contain joints made in glue.

Pattern makers mix with their glue some good, thin drying linseed oil, in the proportion of about one of oil to four of water. The oil is added to the glue and well stirred in whilst hot. This glue is scarcely affected by moisture, and makes a strong, sound joint, although it does not set hard and glassy, like ordinary glue. It is, however, advisable, even when this glue is used, to protect the pattern from moisture, &c., by oil paint, if a good, clean mould is desired.

For large, coarse work, a thin coat of common lead-colour oil paint, with slight finish of black-lead put on dry, is a cheap and simple protection.

Mallet recommends a paint for wheel patterns as giving excellent results in the moulds, and a smooth surface on the castings.

A first coat was applied of a paint made of thin drying oil, spirits of turpentine, and pure white-lead mixed with a little crystallized acetate of copper. When dry this was smoothed off with pumice-stone, then a second very thin coat of the same paint was applied, with the addition of a little copal varnish. The patterns were then slowly dried, being carefully watched to see that no warping occurred. This paint dried very hard, but after a time when exposed to wear and handling it would get scratched, when it ceased to give such good results as those at first obtained. This defect was partially remedied by rubbing the surfaces over with powdered French chalk.

Some patterns, made of rather hard wood, such as dry mahogany, will deliver very well if well coated with copal varnish.

Weak shellac varnish is also a capital protection to patterns; it is easily made by dissolving 1½ to 2 parts by weight of shellac in 20 parts methylated spirits. The ingredients take some twenty or thirty hours to mix in cold weather, but the mixing may be quickened by the vessel containing it being placed on a stove or other warm place.

When a pattern is nearly all composed of one material it is by no means difficult to estimate the weight of the casting for which it is intended. A reference to the table of specific gravities and a short rule-of-three sum suffices to give the approximate weight of

the casting in any desired metal, if the weight of the pattern is known.

If the pattern is of a simple form, its cubical contents multiplied by the weight of a cubic inch, or cubic foot of the metal, will give the weight of metal required for the casting; and this is generally the more reliable plan, as it is quite unaffected by differences in the specific gravities of the materials used in the pattern.

It is always necessary to make a good allowance for the excess of metal in the rising heads, gaits or gats, and the like.

When a pattern is made up of several different materials, and is of a form not easily to be measured for its cubical contents, the usual plan is to weigh each of its component parts before they are finally adjusted in position, and the weight of the hard wood, iron bolts and straps, &c., being noted down, the weight of metal required can be arrived at.

TABLE XVI.—WEIGHT OF CASTINGS.

A Pattern weighing 1 lb.	Will weigh when cast in				
	Cast Iron.	Zinc.	Copper.	Yellow Brass.	Gun-metal.
Mahogany	8	8	10	9·8	10
White pine	14	14·5	18	17·5	17·8
Yellow „	13	12·6	16	15·5	16
Cedar	11·5	11·4	14·5	14	14·5
Maple	10	9·8	12·5	12	12·4

Papier-mâché, or plaster of Paris, should always be black-leaded, over thin, hard, oil paint. Cast-iron patterns should be rusted, by any solution which increases the tendency of the metal to oxidize. Sal-ammoniac, dilute hydrochloric acid, or common salt in water, answers the purpose. The rust must be completely got off by the "scratch brush" of wire, before the black-lead is applied.

All metallic patterns are much improved in their "delivery" by being finely "black-leaded." Prior to the application of the plumbago, the surface of brass or gun-metal patterns should be "roughened," by leaving them wetted with a solution of sal-ammoniac. Zinc, solder, or type-metal, or other such soft alloys,

will "take" the black-lead at once, if the surface be free from grease or dirt.

To preserve iron patterns from rusting, and to make them deliver more easily, they should be allowed to get slightly rusty; next, they should be warmed sufficiently to melt beeswax, which is then rubbed all over them, and nearly removed; they are then to be polished with a hard brush when cold.

The following is a list of the different varieties of wood most suitable for pattern making with their specific gravities:—

	Specific Gravity.
Cork	0·24
American pine	0·37
American fir	0·42
Larch	0·54
Cowrie	0·58
Red Honduras cedar	0·55
Elm	0·55
White poplar	Varies 0·34 to 0·53
Willow	„ 0·42 to 0·5
Sycamore	0·60
Lime tree	0·60
Pear tree	0·66
Cherry tree	0·71
Maple	0·75
Apple tree	0·80
Alder	0·80
Beech	0·85
Honduras mahogany	0·81 to 1·06
Boxwood	1·03 to 1·33

Cast-iron, brass, zinc, plumber's solder, gun-metal, and type-metal are frequently used, whilst cements, plaster of Paris, wax, terra-cotta, papier-mâché, and glass are occasionally employed in pattern making.

Many common works, such as plates, gratings, and parts of ordinary fire-stoves, are made to written dimensions, without any pattern being used, as a few slips of wood to represent the margin of the casting are arranged for the time upon a flat body of sand, which is modelled up almost entirely by hand. But in all cases where accuracy is required, well-made patterns are necessary.

The pattern is a model of which the casting is to be the copy, but an intermediate stage is necessary, namely, the mould, which represents in hollows the projections which must appear on the finished casting. Each of these articles, namely, the pattern, the

mould, and the casting, is generally made in different materials, each of which is subject to certain alterations in size and shape, dependent upon the degree of heat to which it may be exposed, or upon changes in dryness or moisture. Thus, from the original design or drawing a pattern is made, most frequently in wood, which is then transferred to the mould; this varies in materials according to the nature of the work, into which finally the molten metal is poured.

In view of these circumstances, and certain known properties of materials at different temperatures, allowances have to be made for shrinkage, &c., from which it follows that patterns have to be made differing materially from the size and shape of the casting which is to be produced. There are several elements of complication; thus, as there must be a slight clearance allowed for removing the pattern from the mould in which it is enveloped, the hollow of the mould has to be slightly larger than the pattern. The casting itself contracts in cooling to an extent which is pretty well, but by no means accurately, ascertained, and for which a regular allowance is made. Thus, in large, heavy castings, one-tenth of an inch is added to every foot of length in the pattern, which is found in practice sufficient to allow for the contraction of the metal on cooling, combined as it is with the slight increase in the size of the mould over the pattern. In small castings, one-eighth of an inch to the foot, or about one per cent., is sufficient.

The following remarks upon this point are taken, with the accompanying Table, from Thomas Box's 'Treatise on Heat':—

"The contraction which metals experience in cooling down from their melting points to ordinary temperatures is very considerable, amounting to about an inch with a straight bar of cast-iron 8 feet long, or with a copper bar 5 feet long. Allowance has therefore to be made for contraction in fixing the sizes of the pattern.

"Table XVII. gives the result of practical observations on this subject, and is very simple in application. Thus a cast-iron girder 20 feet long must have a pattern $\cdot 1246 \times 20 = 2\cdot 492$ inch longer than itself, but a pattern 20 feet long would give a casting $\cdot 1236 \times 20 = 2\cdot 472$ inch shorter than itself.

"For practical purposes one-eighth of an inch to a foot for cast-

iron, one-sixth for gun-metal, one-fifth for copper, and one-fourth for zinc may be taken as sufficient approximations.

"The contraction of wheels is anomalous, as is shown by Table XVIII. The irregularities in the apparent contraction arise in part from the practice of 'rapping' the pattern in the sand, to make it an easy fit and enable it to be drawn out with facility. This is most influential in its results with small, heavy wheels of great width of face. In some cases, and in rough hands, the casting of a small and heavy pinion may be quite the full size of the pattern. The allowance to be made is therefore not uniform, but must be fixed with judgment. In large wheels, where the effect of rapping is comparatively small, one-tenth of an inch to a foot may be taken safely. A wheel is not so free to contract as a straight bar, and in any case its contraction will be less."

TABLE XVII.—OF THE CONTRACTION OF METALS IN CASTING (BOX).

	Length of Pattern.	Contraction.			
		Total in Inches.	Per Foot.		
			Of Pattern.	Of Casting.	
	ft. in.				
Cast-iron girder	21 8¾	2 11/16	·1236	·1246	..
" "	16 9	2·05	·1225	·1236	..
Gun-metal bar ..	5 4⅝	1·0	·18568	·1886	Maximum.
" "	5 7 11/16	·936	·1653	·1676	..
" "	"	·97	·1713	·1737	..
" "	6 0¼	1·0	·1616	·1684	..
" "	5 6 1/16	·92	·1671	·1695	..
" "	"	·90	·1635	·1657	..
" "	"	·88	·1598	·1620	..
" "	"	·84	·1526	·1545	Minimum.
" "	..	..	·1607	·1632	Mean of 8.
Copper and tin copper, 1·3; tin, 10	5 6 3/16	·895	·1623	·1645	Maximum.
" "	"	·880	·1595	·1617	..
" "	"	·880	·1595	·1617	..
" "	"	·855	·1550	·1570	Minimum.
" "	"	..	·1591	·1612	Mean of 4.
Yellow brass ..	2 9⅛	·5	·1811	·1839	..
Copper	7 10⅞	1·54	·1948	·1980	Minimum.
"	7 5⅛	1·465	·1972	·2005	..
"	"	..	·1972	·2005	Maximum.
"	..	..	·1964	·1996	Mean of 4.
Lead (mould) ..	2 0	·21	·1050	·1059	..
Zinc cast in iron	2 0 3/16	·455	·2257	·2301	Minimum.
" "	"	·465	·2307	·2352	Maximum.
" "	..	..	·2282	·2326	Mean of 2.

TABLE XVIII.—OF THE CONTRACTION IN CASTING SPUR-WHEELS IN CAST IRON (BOX).

Extreme Diameter of Wheel Casting.	Pitch in Inches.	Width of Teeth in Inches.	Contraction.		
			Total in Inches.	Per Foot.	
				Of Casting.	Of Pattern.
ft. in.				inches.	inches.
10 $2\frac{3}{8}$	$3\frac{1}{4}$	12	1·08	·1059	·1040
6 $2\frac{9}{16}$	$3\frac{1}{4}$	9	·54	·0893	·0886
6 $1\frac{3}{8}$	$3\frac{1}{4}$	11	·375	·0613	·0610
5 $5\frac{9}{16}$	$3\frac{1}{4}$	11	·345	·0631	·0628
2 $11\frac{7}{8}$	$3\frac{1}{4}$	12	·11	·03896	·03884
2 $4\frac{15}{16}$	$3\frac{1}{4}$	9	·115	·0397	·0396

The amount of clearance to be left in the mould is much larger in hand-made green-sand moulds, and also with large and heavy patterns, or those which are difficult to draw, than in machine-made moulds, where the difference in size between the pattern and the casting need be little more than sufficient to make up for the contraction of the metal on cooling.

There being so many elements of complication, it is obvious that it would be impossible to give any absolute rules or formulæ sufficiently simple for an ordinary skilled workman to easily understand and remember, in the haste of every-day practice, when nearly every separate pattern that has to be made brings into play different conditions requiring special arrangements. It is in the quickness and correctness of judgment, and the knowledge of the qualities of the various materials he has to deal with, that a good pattern maker is valuable, for although much that it is necessary for him to know can be, and indeed *must be*, acquired from books, yet by far the most important points of workmanship, those upon which the success and beauty of the castings depend, are only mastered by long experience. As a rule, the more varied the experience the more fertile in expedients and resources is the pattern maker, and it is difficult to overrate the saving both in time and materials that can be effected in a foundry, where the pattern shop is directed by a clever, conscientious foreman.

As proving the necessity for experience in this branch, may be taken the frequent instances of highly finished drawings being sent out of the drawing offices of some of the leading engineers to the

founders, where they are contemptuously thrown aside after a hasty glance as impracticable; or, what is still more frequent, some slight modification in detail is suggested, which, without interfering with the general design, materially reduces the cost of the work.

One of the most important points upon which success depends is the allowance to be made for contraction, the extent of which, as before mentioned, varies with the shape, size, and material of the casting.

The allowance is nearly always made by the workmen in the dimensions of length only, although undoubtedly a similar contraction of the metal takes place, to a somewhat smaller extent, in the other dimensions of the casting.

In the majority of cases where the casting is a complete article in itself, perfect accuracy is not imperative. When, however, the casting is intended to be fixed together with other portions, to form an engine, for instance, it is necessary that it should be true in shape and dimensions, and free from flaws and air-holes.

In cases where many castings have to be made from the same mould, the first casting should be carefully examined, and any little errors can then be rectified in the mould before again pouring.

In dry sand or loam moulds this trimming can be managed to a nicety; where they are too slack, by laying on successive coats of clay and black wash; and where they are too tight, by carefully rubbing away some of the sand or loam.

When numerous articles are required to be alike, a metal casting is frequently used as the pattern, as being more durable than wood. In this case a wooden pattern is first made, in which there is an allowance for what is called the "double shrink," that is, the contraction of the *metal pattern* from the *wooden pattern*, and the contraction of the ultimate casting from the mould which has been formed upon the metal pattern.

The shrinkage sideways and endways of a casting 4 inches or less in size, is compensated for by the shake in the sand given by the moulder to the pattern, in order to extract it from the mould.

In very small castings requiring to be of correct size, allowance should be made in the pattern for the shake of the pattern in the sand sideways, say about $\frac{1}{32}$ inch less than the length required.

Shrinkage strains in castings being a subject but little understood, the following original hints, due to Mr. Alfred E. Watkins, upon the subject are of interest.

Many machinists and founders have noticed if a piece be broken from the rim of a pulley, that it cannot be returned without forcing the gap open, showing that the rim had been put under a strain, which caused it to close together so soon as the piece was removed.

The strain here exemplified may be explained in the following manner:—So soon as the pulley is cast, the rim, which is the thinnest, is cooled off by the walls of the mould and sets immediately. The arms containing more metal in a mass, cool next and set. The hub, containing the most metal in a mass, cools last and sets, but in so doing, like all the rest of the metal, has a tendency to contract from its moulded size. It is now easy to see that the shrinkage of the hub will have a tendency to separate itself from the arms, or these from the rim, hence the strain upon the rim is of such a nature as to cause it to close together, and form a circle of less diameter than is natural. When the piece is broken out the strain relieves itself by drawing the rim together. To overcome as much of the evil of this strain as possible, it is usual to curve the arms, which, by straightening somewhat under the influence of the strain, renders them less likely to be broken.

In the case of locomotive drivers, the above was practically demonstrated by some of the leading shops, which found themselves obliged to insert a core between every second or third arm to secure sound castings.

If a piece be broken from a ring no perceptible change of form will take place, the piece can be returned quite readily, and will be found to fit; this, however, does not prove that there is no strain present; on the contrary, we will show there is.

When the ring is first cast, the walls of the mould cool off the inner and outer circumferences, immediately causing them to set, the central core of metal remaining yet hot; in a few moments more it sets, and in shrinking exerts two influences, one to reduce its own diameter and that of the outer crust to which it is attached, and which has already set; and the other to crawl around in the direction of the circumference. whereby, with reference to the outer,

there is a tendency to close together; yet with reference to the inner crust there is a tendency to open outward. Hence, if the ring be put in a lathe, and the outer crust removed, the gap will be noticed to close in, increasing in this tendency as we near the centre of the ring with the tool. As we progress toward the inner crust from the centre an opposite effect will be produced, and the gap will be noticed to open. In a ring of 27 inches diameter, turned till the outer crust was just removed, when the piece was removed, the ring closed together $\frac{1}{32}$ of an inch in 4 inches—two prick-punch marks having been made on its edge 4 inches apart, spanning the place where the piece was to be removed, and before any cutting was done.

Cylinders are no more than deep rings, and the strains explained under rings are also present here.

Ordnance and cylinders shrunk on the Rodman plan will have a tendency to spring open if a piece be broken out, for the following reasons:—By the use of the water core, the interior of the cylinder is cooled first and set; as the material surrounding this central core shrinks it has a tendency to crawl around, as explained under the head of rings, exerting a strain upon the outside—by outside we mean the portion surrounded by the molten metal—of the skin about the core barrel, which strain has a tendency to pull the skin back, or to rupture it; this force is increased as we approach the centre of the section, then retarded and counteracted by the shrinkage of the exterior surface, caused by the refrigerating action of the walls of the mould. This refrigerating action is small when compared with that of the core barrel, hence the tendency to spring open will be somewhat greater than the tendency to spring shut. Therefore, a broken section will always spring open, the tendency being regulated by the greater or less rapidity with which the outer surface is cooled off.

These strains upon rings and cylinders would, if the metal were free to act after the piece was broken out, form an inverted triangle in the face of the broken section, the apex being in the centre of the case supposed under the section on rings; while in the case of the Rodman plan, the apex would be nearer the outer edge, and in a perfect case, should lie just within the outer crust. It is, therefore, best to cast hydraulic rams, cannon, and all other cylinders

intended to withstand great internal force, on the Rodman principle.

Cylinders, with heads cast in, whose thickness is greater than that of the body of the cylinder, will be found to caliper less at the ends than at the middle, owing to the heads, acting as the arms in the pulley, exerting a strain inward, drawing the ends of the cylinder down with them.

If the heads be cast thinner than the body of the cylinder, the cylinder will be found hollow in the middle, owing to the heads setting first, which act as props or pillars, and hold out the ends of the cylinder, while the body being free to contract, will shrink its full allowance.

In the case of a shaft, or other solid cylinder, it will be noticed that the surface of the casting at the ends will be slightly depressed. This is occasioned by the surface of the cylinder being cooled by the walls of the mould first, and setting, while the central portion yet remains fluid or soft. In a few moments more the central portion cools, and in shrinking draws in the ends of the cylinder, the outer crust acting as a prop or stay to the atoms of metal adjacent to it. If this theory be correct, the depression should take the form of an inverted cone, owing to the gradual checking of the shrinkage as it approaches the outer crust. In practice this will be found the case, the obtuseness of the angle being greater or less, according to the nature of the iron to shrink.

The shrinkage strains within hollow, spherical shell castings are similar to those explained under the head of rings, they being no more in fact than rings continued about a central axis. In the case of solid globular castings, the heart or central point within will, usually, be found hollow or porous, owing to the following causes:—The walls of the mould cooling off the outer surface, causes it to set immediately; the interior, cooling from the exterior inward, endeavours to shrink away from the outer crust, which resists its so doing; hence, the interior is kept to a greater diameter than is natural, and there being but so much metal in the entire mass, the atoms are drawn away from the central point toward all directions to supply the demand made by the metal in shrinking.

In the case of flat round discs or plates they will usually be found hollow on the top side, although in some cases the hollow is

on the bottom side. This is owing to the following causes:—The top and bottom faces, together with the outside edge become set first through contact with the mould, leaving the centre yet soft. When the centre shrinks a severe strain is put on the plate by an effort to reduce its diameter, which the outer edge resists. Now, if the cope be thin, the heat will radiate rapidly in that direction, causing the outer or top side to set first; the under side, setting later, will drag the top side over with it, causing it to round up on top and dish in the bottom. Or if the pattern be not perfectly true in every direction, the strains first spoken of will cause any curved portion to become more exaggerated. If the pattern be perfectly true, cope and drag of the same thickness, and both rammed evenly, there is no reason why the plate should not come out perfectly true, the strains being all self-contained in the same plane and balanced. If the plate, however, have an ogee moulding projecting downward around the edge it will likely be depressed on the top surface when cast. This is due to all the surfaces being set alike and at the same instant, excepting the metal within the corners, which, containing the most metal in a mass, will shrink last of all. When this does shrink its tendency is to pull over the top side of the moulding toward the plate, which being soft, although set, will be forced downward at the edges, giving a chance for the strains within the plate, as above described, to aid in the distortion.

The strains are similar in both round and square bars, and are already treated of under solid cylinders. There is another feature, not before spoken of, which is rather curious. If two bars of the same dimensions and mixture of iron be heated to the same temperature, the one allowed to cool in the mould, the other plunged while hot into water, the latter will be found to have shrunk the most. This is due to the particles about the surface having been enabled, by the softness of the interior metal, to get closer to each other than they could have done if the material had cooled slowly.

Rectangular tubes are usually cast with a core, which has a tendency to retain the shape of the casting; still the flat sides will show a tendency to bulge up slightly at the middle. This is due to much of the same causes as explained in the plate with the ogee mouldings, the outer surface is cooled instantly by the walls of the mould, and is set; the inner surface is not cooled quite so

rapidly, owing to the core being of harder material, and not so good a conductor of heat; when this does cool it will pull inward the outer skin of the casting, forming a slight curve; each side acting for itself will produce the same effects.

Gutter or U-shaped castings are made thinner at the edges than at the middle, because the pattern has been made with draught. When castings of this shape are taken from the mould, they will be found rounded over in the direction of their length, the legs being on the curved side. This is explained by the mould cooling and setting the legs first; then when the back or round shrinks it pulls upward the two ends of the casting.

In parallel castings of any length, having a cross-section similar to a wedge, or similar to a "knife" in paper-mill work, the thick side will invariably be found concave and the thin edge curved. This is due to the same cause as explained above. The thin edge is set as soon as cast, the thick edge, cooling later, shrinks and draws the ends of the casting upward, and with them the thin edge, which acts as a pillar to resist further shrinkage.

All ribs have a tendency to curve a plate if they be thicker or of the same thickness as the plate, owing to the fact that whatever shrinkage strain they possess, is below the general plane of the shrinkage of the plate itself. If the ribs be thinner than the plate they will cool first, and by resisting the shrinkage of the bottom of the plate cause it to curve upwards, or "dish" on top.

In conclusion, Watkins offers the general laws regarding shrinkages. The most metal in a mass always shrinks last, hence, if a casting be composed of irregular thickness it will be liable to be broken by the forces contained within itself. It is, therefore, especially necessary that columns and castings, supporting or resisting great pressures, should be so designed as to prevent this great error. Mouldings on columns are often so badly designed with regard to this matter, that the columns are excessively weak where they should be the strongest. As a rule, mouldings should seldom be cast on a column, but rather bolted on. Much of the irregularity of flat castings and those of irregular shapes could be remedied by a proper attention to cooling the castings while in the mould. To be sure this is done to a certain extent, though few moulders know why they do so. They know that by removing the sand from a

particular casting it will straighten in the shrinking. This is but the result of experience, not of thought or any attempt to know why they so act. It is useful to know also that all shrinkage takes place while the casting is changing from a red to a black heat.

Good glue should be clear and transparent, and of a light brown colour, and is an indispensable material to the pattern maker.

Break the glue into small pieces, and soak it for twelve hours in as much water as will cover it, then melt it in a glue-pot, a double vessel; the outer vessel, which contains simple water, is used, so that the temperature to which the glue in solution is exposed cannot exceed that of boiling water. Let it simmer gently from one to two hours; when prepared it should be kept covered. The strength of a well-made glue-joint frequently exceeds that of the solid wood; mahogany and deal are considered the best woods to hold with glue. Glue applied to the end grain of wood must be used much more freely than if applied in the length of the grain, as the wood absorbs a considerable quantity by capillary attraction. End-grain glue-joints never hold so firmly as when the joint is in the length of the fibres.

In making long joints, the parts to be held in contact must be planed very true; the glue is then applied, the two pieces held firmly together, and as much of the glue forced from between them as possible.

Weights and screw clamps are employed to keep the pieces in their proper position until the glue is quite dry and hard.

A useful adjunct is a steam glue-oven. It can be arranged in various ways, the form shown in Fig. 4, Plate XXVI., being that adopted by John Richards and Co. By the means that are here employed, the ovens can be placed on upper floors of large establishments without the danger of fire. The ovens are constructed with double plates throughout, the pots thereby not coming into contact with either steam or water. This also is security against the possibility of leakage, there being but one joint in the whole oven, and that a flat one situated where the apparatus is bolted at the bottom. The steam chamber is one casting. There are waste and steam pipes fitted each side, and in the front is a cock for drawing off any hot water. The pots are of iron, zinc plated; the edges being turned, making a tight joint, prevents any loss of

heat in that direction. The central pot will hold one gallon, and each of the end ones one-third gallon. A zinc water-bucket is also provided. The pressure these ovens can stand is 60 lbs. to an inch without leakage, but the steam chamber is tested considerably beyond this. A great number of these ovens are in use, having mostly taken the place of the old forms, which caused damage by leaking.

In well-fitted pattern shops, as we have remarked, a special set of machine tools may be employed with advantage, and such a set as made by John Richards and Co., of Manchester, is shown on Plate XXVI.

A small face lathe is represented in Fig. 3, and is a very complete and useful machine, taking the place of a double head lathe in a large proportion of the turning incidental to a pattern shop. The expense of this machine is not nearly so great, it occupies but very little space, and is more efficient in every way for any kind of face work of 16 inches or less in diameter. In working this lathe the operator stands directly in front of it, and not at the side, as in other lathes; this makes it doubly convenient for him, especially where face work and inside turning are concerned. Where a considerable amount of pattern turning is done, these lathes are invaluable; even if a double head lathe would perform all the work, a great saving of time and labour is experienced by having them both in use, as a single lathe is generally at work when odds and ends are to be turned.

All lathes are provided with overhead shaft, rest stands, and other details.

The prices are exceedingly low, and the lathes are warmly praised in the establishments that have them in use.

These lathes are also suited for hand-turning in working metals, brass and composition work especially. For this purpose they are fitted with a universal chuck to hold pieces from 4 to 8 inches diameter as required.

Fig. 1., Plate XXVI., shows a pattern-shop lathe made especially for that kind of work. At each end of a running spindle is provided a face plate and also a floor rest, the latter not shown in the figure, so that even large pieces of work may be turned on the overhanging face plate.

The main framing is of iron, planed true on the top, with

grooves and ways to receive the sliding head and rest stands. The latter are quite a new thing, and made very ingeniously, so that the rest and slide are both fastened by a single screw in front.

When necessary, these lathes are fitted with a slide rest, such rest being required in turning parallel pieces, and this attachment is to be recommended.

The lathe shown in Fig. 2 is a large face lathe, and is adapted for use in all establishments where large circular patterns are required to be made, such as gear for water-wheels, pulleys, and the like. The lathes are made to swing to 6 feet diameter on the inside of the rest, when it is in the same position as in the figure, but when swung back, it can be made to swing a much larger diameter. The rest is on a pivot, which enables it to be removed and fitted on at a moment's notice; this is useful in mounting or removing pieces from the lathe, and also enables the machine to be used in turning pieces of more than 6 feet in diameter on the back and periphery.

The main frame is a single casting, and the counter-shaft placed inside; the spindle is 3½ inches in diameter, and the upright is of brass; the pulleys are made of wood, to avoid the extra weight that would be entailed by the use of iron ones, but the latter can of course be used if preferred. Every lathe of this class is provided with three face plates, one stand, and four rests. A floor stand is advised when larger pieces than 6 feet diameter are to be turned.

Wheel patterns are considered less indispensable than they once were, owing to the large introduction of moulding by machinery; but wherever the production of wheel patterns is in large demand, as it long must continue in most colonial foundries, it will be found highly advantageous to combine with this face lathe, a well-made and accurate dividing plate, by the use of which an enormous waste of time on the part of the pattern maker in "stepping round" with spring dividers, the spaces for the teeth of spur or bevel wheels, or those for the "core-prints" in mortise-wheels, may be avoided.

Before being used, every precaution should be taken to ensure the accuracy of a wheel pattern, as to its perfectly circular form, shape, and pitch of the teeth, and the central position of the hub, &c.

The shape of the teeth of some wheels intended for delicate machinery, where accuracy of pitch, and noiseless revolution are important, is drawn with the utmost nicety, but it is obvious that no skill on the part of the draughtsman will make a wheel work "sweetly," if the pattern maker does not strictly adhere to the epicycloids or other curves shown on the drawing.

Besides lathes, there should be one or two circular saws, a band-saw, and a good "general *joiner*" machine.

CHAPTER XII.

MATERIALS USED IN MOULDING.

The principal materials used in the various branches of moulding are, sand of various kinds, clay, blackening, coal-dust, and cow-hair.

The material of which the mould is constructed must allow of the passage of air and gases which are generated within it at the time of pouring, but must also be of a sufficiently compact nature to resist the pressure of the liquid metal, and to prevent its exuding through the pores. It must be capable of bearing the very high temperature at which iron is poured without being affected by it, and it must not be of a nature likely to set up any chemical action with the molten metal. It must be easy to part from the casting, and must give a clean, smooth surface to it.

Sand is superior to all other substances as a material for forming moulds generally. For, in the first place, the hot iron has no chemical action upon it, though, certainly, it acts upon the matters which it is found necessary to associate with it, namely, blackening and coal. But, secondly, it acts well as a conducting medium for the air expelled from the space filled by the iron, and for the other gases generated by the action of the heat on the blackening and the coal. And, thirdly, it possesses considerable adhesiveness when rammed together, sufficient, indeed, to make it retain its form against the pressure of the melted iron; and, moreover, it is easily made to conform itself very accurately to the surface of the pattern imbedded in it.

The locality of many an important foundry has been determined by the proximity of suitable moulding sand in large quantities, for it is evident, that a great deal of the success of the casting operations, depends upon the selection of the proper moulding sand, and upon its preparation for use.

The higher the temperature of the metal to be cast, the more

difficult it becomes to comply with the necessary conditions in the sand. Cast iron is poured at a higher temperature than most other metals which are *cast*, except steel, the moulds for which are prepared in a special manner.

Confining our attention at present to sand for use in moulds for cast iron, it consists principally of silica, magnesia, alumina, metallic oxides, and lime, and upon the varied proportions of these, with occasional admixtures of other substances, the quality of the sand depends.

A large proportion of silica gives a refractory sand, but beyond a certain percentage the cohesion is so much lessened that it is difficult to form the sand into a compact mould, it cracks in drying, and is not therefore impervious to the liquid metal.

The magnesia and alumina are useful, as they render the sand plastic and cohesive.

Magnesia is very refractory, and cements the sand very thoroughly, so much so, indeed, that if it exists in too large a quantity the porous nature of the mould will be lost, a result most carefully to be avoided.

Alumina, from its tendency to vitrify at high temperatures, is also to be avoided in large proportions.

Metallic oxides impair the refractory quality of the sand, more than 4 per cent. should therefore cause a sand to be rejected which contains it. Lime, if it exists even to the extent of 1 per cent., is equally objectionable.

Consequently the principal element of a good sand should be silica, with a little magnesia or alumina.

Sheffield ganister, which is used for lining the Bessemer converters, contains about 85 per cent. of silica, the remaining constituents being magnesia and alumina in nearly equal parts.

Sands for stove-dried moulds have generally more alumina and oxides in their composition.

The best moulding sands to be found in England occur in the coal-measures, and in the new red sandstone; but very fair moulding sands are to be found in the greensand, chalks, and also above these.

The sand of the London basin is also among the finest in the country. It is universally employed in the manufacture of fine

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goods, as grates, fenders, and the like. The sand in the neighbourhood of Falkirk is coarser and more open in the pores, which unfits it for such work. It is employed for casting hollow ware—pots and kettles, for example—as the enclosed air escapes freely through the inside body of the sand in the moulding of such articles. It affords a beautiful smooth skin to the castings from Scotch iron, so remarkable in the hollow goods of the Carron Iron Works in Stirlingshire, and the Phœnix Iron Works at Glasgow. The Belfast sand is finer than that from Falkirk, and is used principally for fine machinery castings. It is also sometimes used for facing the moulds of ornamental work, to give a fine surface. It is, besides, excellent for hollow moulding, when it is fixed with the Falkirk sand; but it is too expensive for general adoption in that way. It is a mixture of a very fine adhesive sand, and one of a more open kind. Derbyshire, Shropshire, Lancashire, and Cheshire produce excellent sands.

One great desideratum is, that these sands should not be liable to what is called "burning" in use, when they will only do duty once with any safety. This defect arises from the crystals in the sand not being sufficiently refractory to stand a high temperature, owing to which they break up into fine dust, which, if wetted and used again, will set in a close and compact mass, and spoil the casting.

As sand from the new red sandstone possesses the quality of durability, it is generally preferred; that which has not been long exposed to the action of the atmosphere is considered the best, and occasionally the softer layers of the red sandstone itself are ground up in the loam-mill, and sifted; sand thus obtained is supposed to have a more crystalline texture than that dug from the superficial sand-pits.

The larger the casting, the more necessity there is to select a reliable quality of sand, as, owing to the great pressure of metal on the sides of the mould, and the length of time which elapses before it gets cool, it not unfrequently happens that the face of the mould fuses, and forms a blister on the face of the casting, which is extremely difficult to remove by chipping.

Rock sand, the debris of abraded rock, and free sand from the sea-shore, are employed for making cores. The former by itself does very well for short cores which open into the sand of the

mouldings at both ends, as it contains a proportion of clay in its composition, which gives it cohesion. But it requires to be moderated with free sand, to make it more open for the better escape of the air in its pores, when used for cores of considerable length, which, of course, are surrounded on all sides by the iron, except at the small portions of the extremities, by which alone the air can find exit. Free sand is also used alone for such cores, but it wants adhesiveness; it requires to be tempered with clay-water, barm, or the refuse of peasemeal. In the use of the last, accuracy is required in proportioning it. The first is used in ordinary cases, and the barm only in very particular cases.

Parting sand should be of a lighter colour than the moulding sand, and should be clean, fine grained, and of uniform texture, free from salt and chalky matters. Red brick-dust, fresh free sand, or blast-furnace cinder, finely pounded, may be used. In any case, the substance used must be one which does not retain moisture. Green-sand moulds are faced with oak-charcoal dust ground to an impalpable powder. Dry sand or loam moulds are faced with wood-charcoal dust ground to powder, or with a blackwash consisting of coal-dust mixed with water.

In County Down, Ireland, they obtain red sands from the new red sandstone. Good sands are also found in Lanarkshire in Scotland. In France the sands are obtained from the tertiary formations. While in Germany they use different kinds, but principally red sands from the new red sandstone. For facing-sand, they mix fine-grained quartz sand with ground-up old steel crucibles, moistened with a little clay-wash. The whole is ground and mixed with anthracite coal-dust! For moulds for cast steel, it is necessary to make a special facing from infusible quartz sand and clay.

In selecting sand it is necessary to avoid that which contains crystals of gypsum; if it contains salt it must be thoroughly washed before use.

Felspar, chalk, iron pyrites, and coal must also be carefully avoided.

Moulding sand is always mixed damp, with a proportion of coal or charcoal dust; ground bituminous, or rich, hard splint-coal, being preferred. Where wood fires are employed, the soot from

their flues is occasionally employed for this purpose, but this, of course, scarcely ever occurs in England.

The proportion of carbonaceous matter to the sand varies, and depends partly upon the quality of the sand itself, and partly upon the uses to which it is to be applied. One part coal to 10 of sand, and 1 part coal to 15 sand, are about the maximum and minimum proportions for the sand floor of the moulding shop. In facing-sands, the variations range over a large field; from 1 in 10 to 1 in 20 may be considered the maximum and minimum proportions.

Every time the sand is employed, that portion of the coal-dust in it which is contiguous to the casting undergoes a chemical change, which is called "burnt," by the moulder, consequently frequent additions of fresh coal-dust to the sand are necessary. For this purpose the sand should be damped, and dug over, and allowed to get cool, and then the new coal-dust must be well mixed in with it.

It is useful to know that a cubic foot of coal-dust, moderately dry and ready for use, weighs about 72 lbs.

The use of the coal-dust is to supply a binding but porous material, which shall be of service when the sand and clay of the mould shall have been intensely heated and perfectly desiccated by the flowing metal. Many other substances have been proposed and tried, but no one of them has proved superior to coal-dust.

Blackening and coal-dust are employed to resist the penetrating action of the iron on the sand. Blackening is simply charred oak-wood ground to powder. Oak charcoal is superior to all other ordinary wood charcoals for the purpose, as it is the heaviest. Other wood charcoals are apt to become disengaged from the surface of the mould to which they are applied, and to float in the iron while liquid, which of course defeats the object of their use.

According to Mr. Mushet's experiments, oak produces 22·6 per cent., that is fully one-fifth of its weight in charcoal. Were the iron allowed to come into direct contact with the sand of the mould, it would enter its minute interstices, and thus yield but a rough surface. To avoid this, blackening is dusted over the surface of the mould, pressed down upon it, and smoothed, in cases of green-sand castings, but it is mixed with clay-water for covering loam-mouldings. Its essential property as a protector of the sand is its

inflammability. All combustible solid substances peculiarly resist liquid iron, as may be exemplified by pouring it over a smooth surface of wood. It rolls about as lively as mercury, on account of the continued effusions of gaseous matter by the combustion of the wood heaving up the iron from the surface. Now, in cases of heavy castings in green sand, as the action of the metal becomes too powerful for the blackening, this is assisted by coal-dust, which is mixed uniformly with the sand in the proportions already given.

Oak charcoal being expensive, many attempts have been made to substitute other materials for blackening; none of these have been very much employed except carbonized peat. A method of treating peat for this purpose was described by Mr. C. E. Hall in a paper read before the Society of Engineers in 1876, and it was then stated that peat blackening had been used for light and heavy castings and cores, with marked success.

Both charcoal and coal dust are rather dangerous materials to keep in store, especially the former, which ignites with great facility in dry weather. It is, therefore, exceedingly advisable to keep these combustible materials in a brick or stone vault, away from any danger of an accidental spark, or the dropping of ash by a careless man smoking a pipe.

In large castings, the blackwash on the face of the mould should be proportionately thicker than for small ones, to allow for the longer continuance of high temperature to which it is exposed, but even this precaution will be of little avail if the moulding sand is not of a very refractory nature.

For castings, where the temperature of the metal is likely to exceed that of melted cast iron, it is advisable to make a special facing of quartz and refractory fire-clay. An infusible facing-sand is made of the silicious ganister and fire-clay wash; dry and screen, then add coal-dust or ground charcoal.

After sand, loam is the founder's great material. As with fire-clays, a chemical analysis of all loams and clays should be obtained before any large purchases of these materials are made. An experienced moulder will generally be able to form a pretty correct judgment as to the qualities of these articles, testing them by observing their plasticity or capacity for taking and retaining impressions.

The clay generally used is either calcareous or ferruginous;

when it contains a considerable proportion of sand, the mixture is called loam. At a red heat these substances part with their combined water; most of the chalky clays fuse at the melting point of cast iron, or become vitrified.

The ferruginous clays, or such as contain alumina and silica, are more refractory. Pyrites and limestone are objectionable in clay or loam, and flinty pebbles should also be removed before the clay is ground in the mill.

The clay should not be allowed to get hard and dry in the store or stack, as it is much more difficult to get it to a proper consistency afterwards. Lime and alkalies are to be avoided, and any clay containing more than about 5 per cent. of carbonate of lime should be rejected.

Clays which do not contain any sand require to have some ground in and mixed with them; and nearly every clay requires a certain proportion of sand to be added to it when ground up.

For giving the necessary porosity to loam, a number of substances are added to it. Amongst them may be mentioned powdered coal and coke, horse-dung, straw, chaff, plasterers' hair, bran, and chopped tow, the material employed must not be cut or ground up too fine, or it will lose some of its binding power, and it must be uniformly mixed throughout the mass of the loam. These substances are only added to that part of the loam intended to be used for the body of the mould, and not to the loam which is used for finishing the face of the mould. The loam-mill has, therefore, two functions to perform, namely grinding and mixing.

An ordinary mortar-mill is generally used for the purpose, but there are several modifications in detail, which are of advantage for loam-grinding purposes.

The rollers should be made hollow, of chilled cast iron, with discs of metal at the sides to prevent the loam from getting inside on to the axle bearings. The revolving pan should be provided with a false bottom, made in halves, so that when worn it can be replaced by a new one, with very little delay. Means should be provided for raising and lowering the rollers to the required distance from the pan to regulate the grinding power. The rollers are placed at different radial distances from the centre of the pan, so that, as the latter revolves, each roller moves in a separate path, and

there are scrapers fixed inside the pan, which turn the contents over and over, and direct them towards the rollers.

In some places separate mills are used for mixing after the grinding of the materials has been performed separately. The vertical rollers are then replaced by discs having a number of arms projecting from their side surfaces, so that as they revolve these arms turn the ingredients over and over in the pan, and thoroughly mingle them.

A greater portion of the mixing of the sands, &c., used for fine work is done by hand, and this is especially the case with facing-sands, which a careful moulder superintends himself.

Loam is usually wetted with cold water when in the mill, but in the winter it is found advantageous to use warm water for this purpose, or to blow waste steam over it from a jet-pipe, as it not only facilitates the grinding and mixing, but considerably assists the moulder in his work; as he *must* handle the loam, if it is mixed with water only just above freezing point, his hands get so benumbed as to seriously hinder his operations, besides causing him unnecessary pain and inconvenience. Of course by the time the loam is delivered into the moulding shop, it will have lost a considerable portion of its heat, yet it can be readily delivered at a temperature of between 60° and 70° Fahr., beyond which it is not necessary or advisable to go, as at much higher temperatures the loam loses some of its cohesiveness.

If the loam has to be left in the open all night during frosty weather, it should be covered with coarse matting or bagging to prevent its freezing, which, however, it is much less liable to do if it has been mixed with warm water.

In cases where a foundry possesses its own clay-pit, the clay is frequently "weathered" by being cut up and exposed to the action of the winter's frost, until it is required to be ground and mixed, this somewhat facilitates the latter operations.

Where unbaked clay-bricks are required for loam moulding, dies may be prepared of various sizes and forms likely to be useful, as a stock of these bricks saves the moulder's time in cutting and trimming his moulds.

The power of conducting heat is considerably less in red-hot iron than in copper and brass, and therefore the moulds for the

latter require to be in a drier condition than those which may be used for iron. Ironfounders' moulds are therefore more moist, and the sand they use is coarser and more porous than that of the brassfounder.

Moulds made of metal are frequently employed for casting tin, lead, pewter, zinc, and types. Brass or bronze moulds are generally preferred for such purposes to iron moulds, as they do not corrode, and retain a better polish. Such moulds are constructed on the same principle as sand moulds. If a metal mould is divided into several parts, each part should be provided with a long handle to protect the hands from the heat of the mould. All the parts must be accurately fitted together, and kept in position by means of lugs and pins, or by wedges.

Gently heat the mould before pouring metal into it; this is especially necessary when casting metals having a low melting point, as they have not much heat to part with between the melting point and the temperature of solidification.

Polish the mould after each cast, and rub over with a rag and oil or tallow so as to slightly grease the face of the mould. Sometimes a film of sandarach, beaten up with the white of egg, is applied, particularly for alloys.

For single metals oil or fat is preferable.

Some few objects are cast in open mould, so that the upper surface of the fluid metal assumes the horizontal position the same as other liquids. As a general rule, however, the metals are cast in close moulds, so that it becomes necessary to provide one or more apertures or *gates* for pouring in the metal, and other apertures to allow for the escape of the air displaced and the gases generated by the inflowing metal.

When these moulds are made of metal they must, except for chill castings, be heated sufficiently so as not to chill or solidify the fluid metal too hastily; and when moulds are made of earthy matters, although moisture is required in their formation, it must all, or nearly all, be evaporated out before they are filled with molten metal, or explosions of steam will occur.

Moulds consisting partly of loam or sand and partly of metal are frequently employed. Small wheels, boshes for cart-wheels, &c., receive their bore by being cast over an iron or steel core.

Such a core-iron is a little tapered, to admit of its being freed from the casting by a smart blow of the hammer.

The casting must not be allowed to cool down entirely before the core is removed. It is generally removed when the casting is hot, but so far cooled as to resist the drawing out of the core-iron.

Many of the difficulties met with in casting would be got rid of if it was possible to prevent the formation of gas within the mould whilst pouring and afterwards. To a certain extent the Americans appear to have done this. Mr. Babbitt uses old fire-bricks, which, after say ten years' service, have not changed colour; any fire-bricks at all discoloured he rejects.

He grinds these to powder, and uses pipeclay as the binding material. He thus gets a pure refractory material, of which he makes his mould; this is heated to a red heat, and then receives the metal whilst red hot. It is said that no gas is generated by this process.

Another American founder imports kaolin, china clay, from Devonshire, and treats it in a similar manner to that above described.

In processes of green-sand and dry-sand moulding, boxes or flasks are always employed, the purpose of which is to contain the sand in which the pattern is moulded. These boxes are, for convenience, of various sizes. If there be a great or constant demand for castings of one form, boxes are made expressly for them, corresponding in form. By this plan a saving of labour is effected, as the ramming up of useless corners is avoided. For general purposes boxes are made rectangular, and in two halves, as shown in Figs. 5 to 8, Plate XXVII. These boxes have neither top nor bottom, but each half box, or, more correctly, each box is composed of an outside rectangular frame, *a b*, which is generally 3, 4, or 5 inches deep, for the lighter flat moulding. They have transverse ribs joining the opposite sides at equal distances of 4½ inches between them. The object of their being open on the upper and under sides is to allow the application of tools for ramming the sand in the box; the ribs being at the same time sufficient as holding surfaces for the sand, which is formed into a close and adhesive mass by the ramming, and, in a manner, dovetailed into the ribs. The rougher, therefore, these boxes can be made the better; they hold the sand

more effectually, and accordingly, in casting the boxes themselves, the patterns for them are simply laid in the sand on the ground, and after being rammed are drawn out. There is no blackening used for the surfaces of the moulding, and thus the iron enters the pores of the sand and roughens.

As there is no covering for the mould, it being exposed to the air, this mode of casting is called open sand casting; the exposed surface, however, is very irregular and rough, so that this mode of casting is used only for moulding boxes, where the roughness is a virtue, and for articles of a coarse nature. Wooden boxes or flasks are also in use, but not commonly in large works. In these nails are made to project inside to increase the adhesion of the sand, and the same plan has been applied to iron boxes, but it is not a good one.

Fig. 8 is a longitudinal view and partial section of a pair of boxes, in which it is seen that the ribs of the upper box are not so deep as the outside frame. They are generally an inch less deep to allow a depth of sand over the pattern that is imbedded in the sand of the lower box. The frame of this box, called the drag-box, is the same as that of the upper, but the ribs are much shorter and thicker, as it is not required to be moved about and inverted like the upper one; besides, it allows a much more available depth of space for the moulding of the pattern. As the lifting and shifting of these boxes, when small, is usually managed by two men, they have two snugs or handles at each end, seen in the Plate, by which they are held. They have also usually three hooks and eyes *n n*, and three pins and holds to receive them, arranged alternately along the sides, there being two on either side and one over the other. The pins are fixed on ears *d, d, d*, cast on the sides of the drag-box, and pass through holes made in ears in the upper box, which correspond, so that the boxes, in being placed together, must always have the same relative position. These pins are often chilled to make them more durable, and one made square while the others are round, which ensures accuracy of position. The hooks and eyes hold the boxes tightly together for the casting.

Flasks must be designed, so as to ensure absolute safety to withstand any pressure that may be brought upon them, not only from the weight of metal pressing upon them, when they are in their

proper vertical position in the pit, but also to withstand any accidental shock or increased pressure, that might be brought to bear upon them in consequence of a sudden blow or alteration in the strains, due to some temporary disturbance of their equilibrium.

They must also be accurately fitted at all points of junction; with this object the edges should be accurately planed, and attention should also be specially directed to the economy of loam that has to be built up for the cope, as the upper box is often called, by reducing the distance, as far as possible, between the exterior of the pattern and the interior of the flask. The boxes or moulding flasks are found to accumulate to a very troublesome extent in some foundries where miscellaneous engineering machines, tools, or engines are the staple productions. These are not only heavy, cumbersome, and bulky, but often represent a large amount of capital lying idle in the worth of mere metal alone.

The only reason for storing these boxes, instead of at once breaking them up and melting them in the cupola, is that they may be, and frequently are, required for use again. It is therefore obvious that such of the boxes as are deemed worthy of preservation, are also worthy of being neatly stacked, and systematically registered, in such a manner as to be easy of access and removal whenever required.

A numbered catalogue of the boxes in stock, with just sufficient description for identification as to size, weight, and purpose of each, should be kept, and a label marked with the corresponding number should be affixed to the box when it is returned to the yard.

The more precise the information that is booked about each article, the less waste of time, that is *money*, will be incurred when searching for it at a future period.

In stacking the boxes, room should be left for the workmen to pass down passages between them, so as to be able to see the labels, and easily remove the box or boxes they are in search of. The yard should be provided with light iron tramways, and trucks, running in the most convenient directions to deliver the boxes to the moulding shops, and in large works an overhead gantry should be provided for the same purpose. According to the nature of the work in use in the establishment various matters of detail will suggest themselves to an intelligent foreman, and in any case it is

certain that to allow an accumulation of boxes to form in the moulding shop or elsewhere, without order or method, involves a much larger eventual expenditure of labour and anxiety, than to have a frequent, almost daily, clearance, stacking, and recording of the boxes, whose duty is, for the time being, completed.

Periodically it will be found advisable to examine the stock, and to remove and break up such of the boxes as it may be considered are not likely to be of any further use.

The boxes should be cleaned before stacking, and should be kept a little from the ground, by being rested upon a few bricks or blocks of wood.

Figs. 1 to 13, Plate XXVIII., represent the different kinds of tools employed by flat moulders in the execution of their work. Fig. 5 is the trowel, the instrument in most frequent use by moulders. There are various sizes of it used, from one-fourth to 2 inches broad in the blade, and 3 inches long generally. The purpose of the trowel is to clean away and smooth down the surface of the sand, to press down and polish the blackening, repair injured parts of the moulding, and so on. Fig. 6 is another form of trowel, of a heart shape. It is particularly employed for entering acute angles in a moulding, into which the square trowel evidently cannot go. Fig. 8 is another form of tool for managing hollow impressions in the sand. Fig. 3 is the form of the sleeker and cleaner. As the trowel is applicable only to open, plain surfaces, this tool is used for cleaning and smoothing sunk surfaces in the sand which the ordinary trowel cannot reach, as the impression of a flange, or of any flat part of a pattern presented edgewise to the sand. The upper end is applied to the sides of such an impression for sleeking or smoothing it, and the under end goes to the bottom, where it is used both for taking up loose sand lying there, and for pressing and smoothing down the surface. It is to be noticed, too, that the upper end is presented edgewise to the direction of the spade at the under end, so that when this is employed at the bottom of a deep recess, the upper end stands sideways to the sides of the recess, and permits free motion.

Fig. 4 is the first rammer; it is about 4 feet 6 inches long, and its under face is about 2 inches by 1 inch. Sometimes the upper end, by being tapered off, is made to serve for forcing holes in the

sand. Fig. 2 is the second rammer, for finishing the work of the first. It is round in the face, about 3½ inches diameter, with a wooden shank of convenient length. Fig. 1 represents the pincers used for laying hold of and shifting about the castings. They have no peculiarity except in having their holding faces round and flat.

Figs. 7 to 13, Plate XXVIII., represent the forms of the cast-iron sleekers employed in the operations of hollow moulding. Figs. 10 and 11 are of the convex and concave sleekers for corresponding surfaces. Figs. 12 and 13 are tools with double plane surfaces at certain angles with each other. Of these there are a variety, having their planes at different angles, to suit the various salient and retreating angles that occur in mouldings. Fig. 7 is a sleeker for the impressions of beads, and Fig. 9 serves to smooth flat surfaces generally. All these have small studs attached to them which serve for handles.

Besides these tools, shovels are used for working the sand, sieves and riddles for refining it, and bellows for blowing off loose sand from mouldings; pots for holding the parting sand and the water used in moulding, swabs for applying this water to the mouldings, being simply tufts of tow brought to a point, and separate linen bags of peasemeal and blackening, through the texture of which these materials are shaken on the sand. There are also piercers or prickers, as they are termed, being pieces of thick iron wire sharpened at one end to a point, for piercing the sand to let off air.

CHAPTER XIII.

MOULDING.

The art of moulding may be divided into two great divisions; namely, green and dry sand moulding, and loam moulding. In the first division, patterns of the articles wanted are universally employed in forming the mould; in the second division, the ordinary patterns are dispensed with, the objects of this division being heavy castings of a regular form; as cylindrical bodies generally, and other circular ware, such as sugar pans and gas retorts.

Large square vessels, water tanks, for example, may also be made by a process of loam moulding. The first division, again, embraces every other variety of article for which there must be patterns. Dry-sand moulding is generally employed for the making of pipes, columns, shafts, and other long bodies of cylindrical form. It is firmer, and better adapted to purposes of this kind than green sand. The material of dry sand is the loam already used in loam moulding, called pit sand, mixed in the mill with an addition of rock sand. It is named dry sand, in contradistinction to green sand, because, after being moulded, it must be dried by heat to fit it for the purpose; whereas the latter is employed as it comes from its native bed, new and damp; the dampness, indeed, is assisted afterwards when necessary, as a certain degree of it is always requisite; but it must not be wet, or approach that condition.

The operations of green-sand moulding are generally recognized under two great classes, hollow moulding and flat moulding. The former includes pots, frying-pans, and every other kind of cooking ware, of a light, dished form. The latter class is very extensive, and is so termed in opposition to hollow moulding. It includes all objects of a flat nature, plate-moulded goods, the various parts of grate furniture, and other ornamental work generally, stoves, smoothing irons, all kinds of machinery that do not fall under

the head of loam or dry-sand moulding, for instance, all the cast-iron work of spinning and loom machinery. In fact, a kind of subdivision exists, known as job moulding, a homely term, including machinery generally and the heavier kind of work, distinguishing them from the ornamental and other lighter work. A steam-engine affords in the parts of it examples of the three kinds of moulding. The steam-cylinder and air-pump which are round, and the condenser which is often square, are instances of loam castings; the fly-wheel, shaft, and the single columns supporting the framing, are examples of dry-sand castings, and the beam, if a Cornish engine, bed-plate, and connecting rod, if of cast iron, are referable to the heavier green-sand casting.

Take, for example, the front of an old-fashioned register grate, Fig. 1, Plate XXIX., which is a familiar instance of light, flat moulding. Its construction is that of two jambs joined at the top by a cross piece. On the back, or inner surface, it is quite flat, and is ordinarily ornamented on the face with raised figures of flowers, or the like. A box is selected that will receive the pattern, and have a few inches to spare, that the pattern may be completely surrounded with sand. The pattern is then laid down, either on the surface of the sand, prepared in the upper box, and which is then termed the false part, which is lying inverted on the ground, or on a flat board of sufficient size to support it in all parts, as in Fig. 2, Plate XXIX. In either case the pattern is laid down on its back. There is next thrown over it a layer of fine sand an inch deep, constituting the facing of the moulding. It is passed through a sieve to detain the coarser parts. Then upon the board, or upper box, which we shall call A, the drag-box B is placed in its proper position in respect to the pattern.

It is necessary to spread the facing of sand before laying down the box, as its ribs prevent the equal distribution of sand. An additional quantity of the common sand is passed through a riddle, which saves the small stones and other refuse in the sand, and the whole is now rammed down by the flat rammer as equally as possible. This is facilitated by a considerable depth of sand having been laid on, as inequalities in the force of ramming are diminished at the surface of the pattern. The box is again filled up with sand and rammed all over with the round-faced instrument. When

the sand is properly set and squared flush with the surface of the box B, the whole is turned over, avoiding sudden shocks of any kind, which tend to loosen the sand, and well bedded on the ground with the box B undermost. The box A, or the board, as it may happen to be used, is lifted off, and the temporary bed of sand in the box A is destroyed. The upper surfaces in the box B, and of the pattern imbedded in it, are cleaned and smoothed by the trowel, so that the surface of the sand is made flush with that of the pattern all round, and also meets the edges of the box. This forms the parting, or place ot separation of the sand in the two boxes; and that they may afterwards separate properly, dry sea-sand is freely sprinkled over the parting surface, and has the effect of preventing the adhesion of the lower layer of sand to that which is superimposed, by entering and drying its pores. The box, which, when made up the second time, is called the cope A, is now laid on the other, guided by the pins, and both are fastened together by the hooks. In bringing them together their meeting surfaces ought to be cleared of sand so as to make them bear freely and steadily. Preparations are now made for the construction of the gates or passages for the iron from the external surface into the mould. In the moulding of a register grate front there are usually four gates *g*, *g*, Fig. 1, Plate XXX., into which the iron is poured simultaneously. The necessity for having so many openings for the iron must be obvious, on considering that iron rapidly solidifies as it cools from a melting temperature, and of course sets in the form of the place it occupies.

To provide for the gates to the moulding, four taper pins of wood are stuck in the sand of the lower box at a short distance from the pattern, projecting upward between the ribs of the upper box. Sand is, as before, thrown into this box, covering the flat side of the pattern, and is rammed between the ribs until the box is filled flush with itself. The pins are now withdrawn, and the holes formed by them are widened at the top into bell-mouths, to receive the iron more rapidly, and are well smoothed there to prevent the metal carrying in with it any loose sand. The upper box is now taken off with care, to preserve the impression of the upper side of the pattern, and the edges of the moulding of the box B, in contact with the pattern, are wetted with the swab to make the sand at

these corners the firmer, and to prevent crumbling on withdrawing the pattern. Still further to facilitate this, as the pattern fits closely in its bed, it must be loosened before being drawn, which is simply effected by taking hold of the pattern by a sharp point, if of wood, or by studs, which are riveted into it when of iron, and gently tapping them laterally and downwards. The pattern is next drawn slowly out of the sand, and it often occurs that the moulding is broken in one or two places in spite of these precautions, and especially if there be much carved or ornamental work on the pattern. The moulder has therefore, in the first place, to repair the damages by adjusting disjointed parts, and making up fractures by the addition of sand. All the more prominent and more exposed parts of the moulding, as the extremities of the ornaments, are treated with a touch of the swab, which must be lightly applied so as not to spoil their sharpness. This process, indeed, with that of applying the blackening, now to be described, are the most difficult parts in the art of the flat moulder. The blackening has now to be applied, and it must be by some means pressed down upon the mould at every part, and made to adhere to its surface. To effect this, peasemeal is used. It is first dusted thinly over the surface of the mould. It rapidly absorbs the damp of the surface sand, and is converted into a pasty matter. The blackening is next dusted over the newly formed paste, and over all, the pattern is placed in its position and pressed down. Thus the blackening is made as smooth as the pattern, and is at the same time held well down to the sand. Channels are now scooped out of the surface of the sand, joining the gate-holes to the moulding; and if the pattern be thin, each channel is widened as it joins the mould, to afford a sufficient inlet for the iron. They are slightly swabbed round the mouth to strengthen the edges against the abrasive action of the iron.

Having finished the moulding, and got it in order for the reception of the iron, the upper box is finally put on the under one in its place, and fastened down upon it. All is now ready for the pouring of the iron. In Figs. 1 and 2, Plate XXX., where the boxes are in this condition, the moulding is represented within, and the gates leading to it from the surface.

There are several points in the practice of green-sand moulding

generally, to which great attention must be paid. In the preceding account, we alluded to the necessity of the sand being rammed as uniformly as possible. Now it may be rammed too closely together, so as to impair its capability of conducting away the confined air and the gases generated by the heat. There must be a degree of ramming applied proportioned to the heaviness of the casting. If the sand be too closely rammed, the current of iron flowing over the moulding is agitated by the air not being allowed to pass freely off. In consequence it breaks up the sand, and heaves it to the surface, and it is easy to see that this produces excrescences on one side of the casting, while corresponding deficiencies exist from the same cause on the other side If, again, the sand be too loosely rammed, the iron by its weight presses it outward off the moulding, which renders the surface uneven and swells the casting. Moreover, a certain degree of humidity in the sand is necessary for the goodness of the casting. When the sand is deficient in moisture, the iron is apt to penetrate its pores on the under surface, and so detach the particles of sand there, producing an effect similar to that occasioned by over-ramming. On the contrary, if there be an excess of dampness in the sand, the iron, by the sudden formation of aqueous vapour, is frequently repelled altogether, and ejected at the gate like shot. Should this not take place, though the iron may make its way through the mould, the bubbles of vapour form cavities in the casting towards the under side principally, as this side bears all the run of the iron passing over it, and is thus more severely tried than the upper side, the iron simply rising to that side, and is there at rest. Excess of dampness, and of over-ramming, are thus nearly alike in their effects, and are the more dangerous extremes. In cases of very large castings, if the air expanded by the heat and the other gases generated do not find a ready vent, they burst through every resistance with explosive energy.

The quantity of blackening to be applied must also be of a particular quantity. In noticing, in a former chapter, the nature of blackening, and the manner in which it is operated upon by the iron, reference was made to the continued evolution of gas by combustion. If then, by the action of the iron upon the blackening in the mould, too much gas be formed, it collects in globules, and

forms corresponding indents in the casting. The skill of the green-sand moulder consists in so laying on the blackening as to produce equilibrium between the antagonistic forces of the iron advancing and the resistance of the gas produced. After having been pressed down by the pattern, the loose blackening is rubbed off and blown away. When this is not attended to, the blackening is raised in layers from the surface by the iron, and deposited in other positions, giving the casting when cool a rough clouded appearance. In forming the surface of the blackening upon ornamental moulding, by pressing down the pattern upon it, care must be taken to have the pattern perfectly dried before being laid over the blackening; for if at all damp, this will adhere to it, and take the peasemeal with it, and so destroy the moulding. And even though it be quite dry at first, yet it may, by lying too long in the sand, contract damp, and so spoil the mould. Swabbing is to be avoided when not essentially necessary, as the formation of vapour by the contact of the iron with the water is, as before noticed, apt to agitate the current, and to make the flow irregular. The object of forming the gate to one side of the moulding, is to check the violence of the iron in motion, and to introduce it with regularity. Were the gate formed directly over the moulding, any delicate ornamental work would be worn off by the continued action of the iron, though certainly it may be so placed if the moulding at that part be plain. We noticed the necessity for a number of gates to the moulding. The number of these varies with the extent of the surface of mouldings in general, and also according to their thickness. A comparatively deep moulding might be well filled by only one gate, whilst another of just the same horizontal surface, but shallower, would require two or more gates. In short, there must be as many gates as are requisite to ensure the metal's having thoroughly filled the mould when liquid. The iron therefore should be run in as quickly as possible to fill the mould completely, and this is especially to be attended to in cases of light, flat, and hollow moulding, as in these the extent of the cooling surface is great, compared with the depth or thickness of the iron.

Before dismissing the subject of light flat moulding, one other elegant example may be described, introducing the use of three boxes for a moulding. The instance referred to is the moulding of

the cast-iron bushes, which are fixed into the naves of the wheels of waggons and other vehicles, to sustain the wear of the axle.

Fig. 2, Plate XXXI., is an ordinary bush for cart-wheels. The dotted lines show the form of the interior, which is a tapered hole. At the middle of the length as shown, a chamber is formed in the bush so as to surround the axle—its object is to contain the grease for lubrication. These bushes are always cast in pairs, and the cores for them are cast-iron pins, having the form of the axles for which they are intended. These pins, which serve for many successive castings, are turned and polished in the lathe, for the purpose of communicating a smooth surface to the interior of the bushes, by which the expense is avoided of boring them out, which would be necessary were sand cores employed.

The pattern of the bush is solid, and has, in addition, a core-print on each end to steady the core. This is shown by Fig. 3*a*. Fig. 3*b* shows the core extended at the ends in correspondence with the prints. Round the middle of its length a thickness of sand is wrapped to form the grease chamber in the bush. This part is made of sand, so as to be separable, and thus allow the core-pin to be driven out of the bush when cast.

The box in which the bushes are cast consists, as already mentioned, of three parts. The length of the middle part is made the same as that of the bushes between the small end and the tops of the feathers. The parts are octagonal in plan, as represented in Figs. 1 and 4, Plate XXXI., where A is the top, B middle, C bottom.

In proceeding to mould the pattern, a flat board is laid down level, with two holes in it at a suitable distance from each other. Upon this board a pair of bush patterns are set down on their small ends, the points passing through the holes in the board to keep the pattern steady. The box B is inverted and laid down over them and filled with sand, which is rammed about the patterns level with the tops of the feathers on them. The box C is now fixed on and rammed with sand. Fig. 5, Plate XXXI., is a sectional view of the boxes and their contents at this stage of the process.

The two boxes together are inverted and set down, the box A is fixed on the uncovered end of B, and it likewise is rammed flush with sand. Two holes are next pierced downwards in the sand with the handle of the rammer, one on each side of the patterns.

One of them extends just through the box A, and the other reaches down to the box C. A and B are lifted together off C, and turned over, the patterns loosened by tapping are next drawn out. A and B are then separated. Two prepared core-pins are next set as vertically as possible into the recesses left by the prints in the sand of the lowest box; on the surface of the sand, at each end of the box B, channels are cut joining the gate-holes, made by the rammer to the two mouldings, in such a manner that the short gate will be connected with the upper end, and the long gate with the under end of the mouldings. B is lowered over the cores and fixed to C, being directed by long guide-pins at the side. A is next replaced, guided also by pins and fixed to B. It must be placed with care, as the upper ends of the cores are at the same time entering the recesses made by the prints, and thus the cores are secured between the boxes A and C.

The moulding as thus finished is shown in Fig. 6, which is an external view of the whole, with the interior arrangements in dotted lines. Fig. 4 is a view of the upper and under ends of the middle box, showing the gate channels. The iron is poured into the long gate, falling against the bottom of it, the force of the iron is broken, and it runs gently into the mouldings, rising within them till they are filled, when it passes into the short flow gate, as it is termed, from which it issues, carrying off the refuse it may have gathered in its passage. Blackening is not applied to these moulds, as their roughness is of no consequence.

The gates for any casting, as we have said, are a matter for particular care.

In the language of the shops, all the passages leading the fluid metal into the mould are called "gates," each of which, however, has its own peculiar name, hence the large opening into which the metal is first poured is termed the pouring gate. The recess below, or in connection with the pouring gate, for skimming the iron, is termed a skimming gate; the little passages from the skimming gate to the mould are sprue gates, usually "sprues" only; and those openings by which the supply of iron is kept up after the casting is poured are called feeding gates.

The form, size, number, and proper arrangement of either or all of these have a decided effect upon the soundness and cleanness of

the casting to which they appertain, and should be arranged as to size and position with especial reference to the sizes, shape, and character of the work in hand.

Most of the following remarks on gates are from the pen of R. E. Watkins, whom we have before had occasion to quote. The pouring gate, being the principal entrance for the iron, will be noticed first. When placing this, it must be so arranged as to admit the metal to all parts of the mould at nearly the same time, hence its position must be central, or as nearly central as the nature of the work will permit.

Its cross-section should be circular, for the reason that this form presents the least refrigerating surface for a given area, hence it is best to retain this form throughout as much of the length as possible, whatever its form at its junction with the casting. There are cases where this form cannot be retained, especially in some classes of loam work; still it should not be deviated from, if at all possible. Narrow flat gates are the worst of all possible forms.

The proper diameter for gates of this class should bear a certain ratio to the refrigerating surface of the mould. If they be too small, the casting will suffer; if too large, unless intended as skimmers, there is a useless expenditure of iron. ~~It is almost~~ impossible to lay down an exact formula for this orifice. Iron in its melted state will necessarily follow the laws governing fluids; hence the usual formula for ascertaining the diameter of pipe for a given discharge will answer in this case also; a constant must, however, be included for each square foot of mould area or cooling surface; for, taking the cases of a stove-plate and a solid ball, each weighing one hundred pounds, it is at once apparent that the stove-plate requires a much larger gate area than the ball, or the metal would be so much impeded by its friction through the passages as to lose its heat, and run thick over the extensive surface presented by the one, as compared with the compact form of the other. For small castings it is probable that little attention would be, or indeed need be, paid to formulæ if they did exist, but in castings of large single-loam work especially, its convenience would become at once apparent.

For some classes of work it becomes necessary to be particular that none but clean iron enters the mould; to attain this end

skimming gates are employed. The forms of these are various, yet when the moulder once understands the principle of their operation, his judgment will at once enable him to design any style that would be most likely to meet his particular case. The principles usually employed are those of specific gravity and centrifugal force.

To attain the end by specific gravity, the pouring gate is made of much larger area than would be necessary if it were to be employed as a pouring gate only; the orifice at the junction with the mould is not, however, increased above that required for the ordinary pouring gate; the metal having filled the gate, the small orifice into the mould throttles down the flood, allowing time for the lighter material to separate from the iron and ascend to the surface of the gate, where it will be found after the casting is poured.

The centrifugal-force principle is employed by forming a chamber between the mould and pouring gate, to both of which it is connected by small channels or "sprues." The shape of this chamber and arrangement of the sprues accomplish the whole end.

In one manner of employing this principle, the chamber or skimming gate is formed by moulding a ball, equally in both cope and drag; the sprue from the pouring gate is then led into it at tangent to the outer edge or circumference, the sprue to the mould is taken out radially from the axis; it is best to take the sprue to the mould out just at the back of the sprue from the pouring gate, that the iron may travel around as much of the chamber, before it is drawn off, as possible. It becomes at once apparent that the metal entering from the pouring gate is thrown violently against the walls of the chamber, which from its shape imparts a rotary motion thereto, and the constant supply of metal causes the iron to take upon itself a rapid spinning motion, whereby the heavier body (iron) is thrown to the outside, where it is drawn off by the sprue, and the lighter body (dross) is forced to the centre, where it revolves about the central axis.

It is, of course, necessary that all the sprues to the mould be taken out of the drag side of the flask, while those from the pouring gate may be either in drag or cope. It is not important that only one sprue should be led from the chamber to the mould, a number may be employed if the nature of the work requires it. It is essential, however, to have the sprues to the mould of less area

than those from the pouring gate, that they may act as a check upon the fluid iron, and give time for the foreign matter to separate.

Feeding gates are employed in large castings for the purpose of supplying iron taken up by the casting in shrinking. Their best position is undoubtedly over some thin portion of the casting likely to be injured by the shrinkage strains, because the hot iron being supplied to that point the longest, will enable the strains caused by the rest of the mass in cooling to adjust themselves without injury to the weaker part.

More than one feeding gate to a casting is unnecessary, for the reason that for every gate added the feed is correspondingly slow, and the orifice more likely to clot up. To secure a clean gate it is necessary for the feed to be more rapid, necessitating the constant supply of fresh hot iron. If, however, two gates be employed, the feed is only half as fast as with one, and the opening will chill up in half the time. If three gates be used the feed in each will be reduced to one-third, and the difficulty of keeping the gates opened will be enhanced three times, and so on for each additional gate, and when the gates are knocked off a blemish, in the form of a shrinkage hole, will be found at the root of each, owing to the chilling up of the gate before all the shrinkage had been supplied. This will not be so when only one gate is used, for the reason that the gate remains open till the last possible shrinkage takes place, and there is no further tendency to strain after the gate has chilled. If a blemish of this sort does occur with one gate, it is because the feeding had not been properly attended to, and the metal was allowed to get so cool before the hot iron was added that the end in view was defeated.

Shrinkage holes usually occur between gates, and are explained by the walls of the gates chilling the mass contained therein before the mass of the casting had ceased shrinking. As the gate chills from the sides and top, it may be likened to a capped pillar, the central part strained away. The top of the gate being exposed to the atmosphere it will chill most rapidly from the top toward the bottom, therefore the softest mass will be that nearest the casting, and that part it is that will supply the shrinkage required by the casting: hence a cavity is the result.

Having given two detailed examples of the mode of moulding and casting light and flat ware, illustrating generally the manner of conducting the manufacture of these goods, the practice of hollow moulding falls now to be described, as that branch of moulding naturally precedes, in order of description, the heavier species of green-sand moulding.

The distinct objects of hollow moulding are comparatively few in number and small in dimensions; there are moulding boxes for them, individually of corresponding shape, generally manageable by one person. Boxes in two, three, or four parts are employed as the necessities of the case may require. We shall select for example the moulding of a three-legged pot, Fig. 7, Plate XXXI. The body of it is nearly spherical, drawn in at the neck and opening towards the brim. It has two ears at the neck, by which it is moved about when in use, and three feet on the bottom. The pattern is an exact model of the pot, being in two halves separating vertically. The patterns of the feet and ears are also loose on the body of the pattern, fitting to it by pins. To form an original pattern, the plan usually adopted is that of moulding in loam, which will be understood when we come to describe this branch of the art. In the mean time it is sufficient to state that the rough cast pattern is chucked in the turning lathe, and turned within and without to the required form and thickness; in doing which it is facilitated by boring four longitudinal rows of small holes through the pattern at equal distances round it, by which its thickness at any part may be always ascertained. Having been smoothed and polished, the pattern is taken from the chuck, and cut in two equal halves, in which holes are bored in the proper positions for receiving the pins of the ears and feet. The pattern is moulded in a box, consisting of four parts named the top, marked A in Fig. 9, the two cheeks, B C, and the bottom D. The divisions into parts is the same as that of the moulding box for axle bushes last described, supposing the middle part divided vertically in two, corresponding with the cheeks B C. The pattern being moulded in an inverted position, the top A is made to enclose the bottom of the pot, as far up as its largest diameters; the cheeks B and C enclose the remaining portion of the pot, and the bottom D serves to close up the mouth of it.

The two cheeks are first laid down on a level board and linked together; the pattern is then laid down on its brim within the cheeks, being raised off the board by a slip of wood, of which the thickness is adapted to bring the largest diameter of the pot to the level of the upper edges of the cheeks. The patterns of the ears are attached, and sand is rammed in round the pattern flush with the cheeks, making the parting surface on the centre of the pot. The surface having been sprinkled with parting sand, the top A is put on, led into its place by guide pins and fastened to the cheeks. Sand is again rammed in to the level of the mouth of the pot, the patterns of the feet and the gate pin being set in their places in the course of the ramming of the sand. Fig. 8 shows the position of things as now described. The whole is next inverted, and the board and slip of wood removed. The surface of sand round the brim of the pattern is smoothly sloped off to the edge of the box forming the parting surface, and the bottom D is fixed on. It is also filled with sand. The body or core of sand filling the interior of the pattern is pierced in several places with a pricker sent down to the pattern, forming thereby channels of escape for the air expelled by the metal introduced. The whole is finally inverted, D lying uppermost, and placed on a flat board with a hole in it to allow the escape of the air. The sand outside the pattern is sometimes pricked, though this is but of little importance.

The part A is now separated and lifted off, carrying the feet and pin with it. The cheeks, B C, are next separated horizontally, taking the ears with them; and the half-patterns are withdrawn from the core. The external and internal moulds thus exposed are sleeked up with appropriate tools, and blackening is dusted on them, and also sleeked up. The patterns of the feet and ears, and the gate pin are drawn out, the boxes B C are replaced exactly as before, and the box A above them, the whole being again bound together. The mouth of the gate is next formed and smoothed. The space occupied by the pattern is now vacant for the metal. Fig. 9 is an external view, and Fig. 10 a section of the box and moulding. In the section are shown the parting surfaces, and the slope of the under one.

All dished utensils are cast with their mouths downwards, and,

in some cases the area of the mouth is so small when compared with the largest diameter, as to render it necessary to bind down the core in the mouldings. For it is very evident that the iron lying so far in below the core, it tends by upward pressure to lift the core off from its base. Such a result would, of course, spoil the casting. This binding is requisite in kettle mouldings in particular. It is simply effected by burying an iron rod in the core, having on it a cross at the end to give it a hold of the sand, the outer end being locked to a transverse piece which bears on the edges of the box.

The metal requires to be at a high temperature for hollow moulding; for so quickly does it cool that the brim of a moderate-size pot sets even before the mould is filled. While yet red hot the casting is taken out of the sand, and the gate piece knocked off. This must be done at a certain stage of the cooling, as when too soon done the gate does not break clearly off, and when delayed too long, it often carries off a piece of the bottom of the pot with it. With a view to provide against this, the pot is made considerably thicker at the centre of the bottom. Flat gates are formed for flat-bottomed ware, frying-pans for example. They are wide at the mouth to receive the iron the better, but taper like a wedge toward the moulding, so as to be easily separated from the casting. By being of considerable extent, flat gates conduct the metal more speedily to the different parts of the mould.

A great improvement was effected in this class of moulding by the arrangements introduced and employed by R. Jobson, especially where a large number of castings are required from one pattern.

In Mr. Jobson's process of moulding, after the pattern has been first partially imbedded in the sand of the bottom box as in ordinary moulding, Fig. 1, Plate XXXII., and the parting surface has been accurately formed, the top box is then placed on, and is filled with plaster of Paris, or other similar material, to which the pattern itself adheres. When the plaster is set, the boxes are turned over, the sand carefully taken out of the bottom box, and a similar process repeated with it, as in Fig. 2, using clay-wash to prevent the two plasters from adhering; this forms a corresponding plaster mould of the lower portion of the pattern. These two plaster moulds may be called the "waste blocks," as they are not

used in producing the moulds for casting, but are subsequently destroyed.

Reversed moulds in plaster, Figs. 3 and 4, are now made from these waste blocks, the pattern being first removed, by placing upon the bottom box a second top box, an exact duplicate of the former top box, and filling it up with plaster, having used clay-wash as before, and doing the same with the other box. Reversed moulds are thus obtained, from which the final sand moulds for casting are made, by using them as "ramming blocks," upon which the sand forming the mould is rammed by placing a third duplicate top box, Fig. 6, upon the ramming block, and a corresponding bottom box, Fig. 5, upon the ramming block.

The requisite gits, or gates, runners and risers, are formed previously in the original sand mould, and are consequently represented in the ramming blocks, Figs. 4 and 5, by corresponding projections or ribs upon the parting face of the one, and hollows in the other, which are then stopped up with plaster, and these are properly repeated in the final sand mould, Figs. 5 and 6; these last therefore, when put together, form a complete mould for casting, just like an ordinary sand mould, Fig. 7, but having some important advantages.

Any number of succeeding moulds can be made from the original ramming blocks by the simple process of ramming, without any handling of the pattern or turning over the boxes, both top and bottom moulds being rammed independently and at the same time if desired. The parting being once accurately formed in the original mould, all the succeeding ones are necessarily correct, without any further care being required; and by carefully trimming the original, and by slightly paring down the inner edges of the parting faces, if requisite, the faces of the final sand moulds have a corresponding fullness, and are readily adjusted, after the first trial, to fit so closely together, that practically no fin is left on the castings. Also the labour of forming the gits and runners afresh for each casting mould is avoided, by having them completely imprinted upon each mould in the process of ramming; and by this means all risk is avoided of imperfect castings arising from want of uniform care or judgment in the formation of the gates, by the moulder in the ordinary process. This is the more important in

the case of difficult castings, where several trials may be required before the best mode of running the metal is ascertained, so as to ensure sound, good castings; and by this process the exact repetition of the same plan is ensured, without requiring any further attention from the moulder.

A small hollow is imprinted in the ramming block for the top box, into which the plug for forming the gate is rested while the box is rammed, and by this means the gate is ensured being formed in the right place, without any care on the part of the moulder.

The process of moulding by this plan is so simple and certain, that ordinary labourers are quite sufficient to make the best castings, as they have nothing to do but ramming the sand upon the two blocks in each case, forming the back and front of the pattern, and putting them together without having to pay any attention to the parting gates or runners; and also it is much easier to lift the boxes when rammed off from the blocks, than to pick out the pattern from the face of the mould as in the ordinary process. The whole being in one solid mass in this plan, it can be lifted more steadily, with less risk of injury to the sand mould.

When the pattern is long and very thin and intricate, as in the case of an ornamental fender front, where the general surface is also curved or winding, as in Plate XXXIII., the difficulty of picking out the pattern from the mould is so great as to require the most skilful workmen, and the length of time required for repairing the injuries of the mould causes about eight sets of fender castings a day to be the general limit to the number that can be moulded by each man and boy. But however difficult the pattern may be to mould in the ordinary way, if it is arranged to "draw" properly from the mould with this process, the labour is very little greater than with an easy pattern; the saving of time is so great that as many as thirty a day are moulded on an average by one labourer and a boy, being four times the number that the best moulders can produce by the ordinary plan.

When the pattern is slender and long, it is liable to be broken in the frequent handling to which it is subject in the ordinary process of moulding, and the expense and delay caused by the breakage of patterns is of serious consequence in light ornamental work, where the patterns are often very expensive; but in this

plan such defects are entirely avoided, the pattern is never handled at all, except by the ordinary process of moulding to form the ramming blocks.

When the face of the castings is required to be particularly well finished, a brass or other metal pattern is made, and is dressed up and finished to the degree that may be required in the castings, and any chasing or other additional ornament put upon it; then, after forming the remaining block for the bottom box, by a plaster cast from the pattern in the manner before described, see Fig. 2, Plate XXXIII., the pattern itself is made from the permanent face of the ramming block for the top box, Fig. 1, by leaving it in the mould, when the plaster is poured in, so that the plaster forms merely the parting face and a solid back to the pattern. In this case, the iron pattern is secured to the cross-bars of the box, by several small bolts screwed up to plates at the back of the box, so that when the plaster is poured in, filling up the whole vacant space of the box, and setting solid round these bolts and over these nuts, the iron pattern becomes so firmly secured in the box, that no ramming or moving it is subjected to afterwards, has any risk of loosening it.

In this plan the mould for the face of every casting is formed from the original metal pattern, and the pattern itself is firmly and permanently secured in the plaster bed, so that however thin and delicate it may be, there is no risk of injury to the pattern in moulding any number of castings: as many as 3000 have been cast without injury from a slender ornamental pattern.

In forming the ramming blocks, common plaster of Paris is most generally employed, as the most convenient and economical material, and this is found to be sufficiently durable for general work; the blows of the rammer are deadened by the sand in the box, and do not fall directly upon the plaster block, so that there is no risk of injury with ordinary care in ramming. As many as 4000 castings have been moulded from one pair of plaster blocks; but when a greater number of castings are required to be moulded from one pattern, or when the size or nature of the mould renders a harder face advisable, a metal face is employed for the ramming block of the bottom box, or for the parting surface of one or both blocks. This is formed simply by running into the mould, when prepared for the plaster, a small portion of metal, consisting of zinc

hardened with about one-fifteenth part of tin; sufficient metal being used to form a strong plate for the surface of the ramming block, and the rest of the space at the back filled with plaster as usual. In practice it is more convenient generally to reverse the mode of running this metal for the face of the mould by first ramming the box, when prepared for the plaster, full of sand, then lifting it off, and paring off the surface of the sand wherever metal is wanted to such depth, about three-eighths of an inch, as may be desired for the metal, and when the box is replaced in its former position, the metal is run in, filling up these spaces where the sand had been cut away. The sand in the upper box at the back of the metal face is then all removed, without moving the box, part at a time if requisite, and plaster poured in above to fill up the box and make a solid back as before.

The metal face is firmly secured to the plaster back by several small dovetail blocks cast upon the back of the metal, by cutting out corresponding holes in the sand mould before the metal is run in. Various modifications of this plan of construction are employed according to circumstances, for economy or convenience, and sometimes the face of the ramming blocks is partially covered by separate pieces of metal; but in every case the entire face of the two ramming blocks forms a perfect counterpart of the intended casting, surrounded by parting faces which exactly fit one another, because the one has been moulded from the other.

When the pattern is long and a metal face is employed, a narrow division is made, subdividing the metal face into two or more lengths to allow for the shrinking of the metal forming the face, the effect of which is then found to be imperceptible. The plaster-ramming blocks are varnished when dried, to preserve them from damp, and in moulding from them the faces of the blocks are dusted with rosin, to prevent adhesion of the sand.

Jobson's process of producing the blocks, though somewhat complicated in description, involves practically but little increase of work over the process of moulding required for the first casting produced by the ordinary method, but every subsequent casting, instead of requiring a repetition of the whole process of the first moulding, as in the ordinary method, is moulded by simply ramming the boxes upon their respective blocks. A better form of the

steady pins for connecting the top and bottom boxes may be adopted, which is easier to construct with accuracy. Instead of four or more round pins fixed on the bottom box, and fitting into corresponding holes in lugs cast upon the top box, vertical, angular studs are cast on each bottom box, and fit against corresponding projections on the edge of the top box, seen in Plan, Fig. 4, Plate XXXIII., and in section Fig. 7, Plate XXXII.; the only fitting required in making the boxes is to file the touching angles of the pins, so as to fit one standard top box and the projections on the top boxes to be all fitted to one stand and bottom box.

It has to be noticed that in the ordinary plan of moulding, and by the odd side and plate methods, one side of a pattern is not available while the other is in use. By Jobson's process each pattern is equal to two, as it will be evident that both blocks may be worked from at the same time.

In taking up the subject of heavy green-sand moulding, we enter upon an extensive field of practice, and it will be necessary, as before, to select such examples as appear best adapted to present fair general views of the subject.

In connection with some observations on the practice of green-sand moulding generally, stated at the conclusion of our notes on light flat moulding, we must here remark the introduction of a new element, powdered coal, namely, into the sand, in a state of simple mixture, its office, as before remarked, being to assist the blackening in resisting the penetrating action of the iron. As this action exists just so long as the metal continues in a liquid state, the blackening alone proves sufficient to resist it in cases of light moulding; whereas in heavy mouldings, there being a much greater body of metal together, its temperature falls so much the less rapidly, and it, of course, continues its action as a liquid for a longer period. Consequently coal-powder in addition becomes necessary to withstand the attack of the iron. But, further, the proportion proper to be mixed is a matter of considerable nicety, and is dependent on two circumstances: first, the length of time that the liquidity of the metal continues has a simple relation to the bulkiness of the metal; secondly, the temperature of the metal on being poured into the mould, does proportionally increase or diminish the original intensity of the action on the sand, as well as

affect the duration of this action. The correct adjustment of this point must be left to the skill of the workman, derived from his previous experience.

A redundancy of coal in the sand renders the surface of the casting formed in it faint; that is, its outlines are imperfectly developed, or, to use again the language of the moulder, the casting is not sharp. This is the natural and obvious effect of the repellent power of the superabundant gas generated by the heat from the coal. On the contrary, a deficiency of coal proves equally hurtful to the quality of the casting, as the gas produced from it is too weak to maintain the well-balanced action of the opponent forces. The iron having burnt through the blackening, penetrates the sand, which at the surface becomes incorporated with the metal, and produces therefore a peculiar roughness on its surface. In order to make the casting in the most proper manner, the sand and coal-powder should be mixed, not only in a proportion suited to the body of the metal to be cast in the mixture, but also as uniformly as possible.

Peasemeal is not generally used in the ordinary flat mouldings, its object being to hold down the blackening applied to mouldings of an intricate or ornamental character. Now the parts of machinery generally have their surfaces plain, which are therefore easily accessible to the trowel and sleeker.

For large castings, the bed of sand which forms the floor of the foundry is commonly used for constructing the moulds, serving thereby the purpose of the drag-box. The chief defect entailed by this method, which is indispensable in some cases, is that the moulder has to work in a very uncomfortable position.

Fig. 1, Plate XXXIV., is an external view of the bed-plate, showing the upper surface of an early form of high-pressure engine, by no means a form to be imitated, but merely given here for illustration. It was arranged to maintain six columns, surmounted by an entablature. At one end, *b*, a flat form for supporting the cylinder is cast across the plate, stiffened by a deep flange at the edge. The position of the cylinder is indicated by the dotted circle. When the cylinder was set in its place, the apertures *c c* formed continuations of the exhaust steam passages, they were joined into one short branch pipe below the platform; *d* is a circular passage

for the introduction of the steam into the valve-chest. It is projected downwards to the level of the mouth of the eduction pipe, both passages terminating in one large flange, by which the respective pipes leading to them are connected.

Fig. 3 is a plan of part of the bed-plate, including the steam-ways, showing in dotted lines the exhaust passage and the flange. Fig. 4 is a vertical section of the plate and the exhaust passage at the line $a' b'$, Fig. 3. The steam passage also is dotted in behind it. Fig. 5 is another vertical section of the same, at the line $e e$, Fig. 3, showing in section both of the passages c d.

Fig. 6 is a plan of another portion of the plate, showing the foundation for a column; Fig. 7 being a vertical section of the same at the line $a'' b''$, Fig. 6. It thus appears that the bed-plate is hollow within, and it possesses the form of section shown in Fig. 4 all round, interrupted only by the sockets for the feet of the columns. It is a general practice in founding to dispose of the moulding so as that those parts of the casting towards which the greater quantity of metal exists may be undermost. In this way greater security is found for the soundness of castings at the more important parts.

Now the bed-plate is, for the most part, entirely open on the under side, as may be seen on referring to section, Fig. 4; and this is particularly the case in modern examples. It ought therefore to be cast with that side uppermost, according to the preceding statement.

For reasons which will be better understood as we proceed, the pattern of the bed-plate, of the same form externally, is not made open like the bed on the under surface. Neither are the oblong blank spaces, shown in the sides, executed in the pattern; its cross-section at every point is a four-sided figure. This form of pattern in the sand will, of course, leave a plain open space of the same breadth as itself. Cores of sand, of the form of the internal void, must therefore be introduced into the moulding to complete the figure of the casting. The Fig. 1, Plate XXXV., exhibits the under side of the pattern. At a the patterns of the steam-ways are placed. They are not fixed to the surface on which they stand, but are simply prevented from shifting laterally by small pins or snugs. They are made solid, so that they too, like the plate itself, require to be cored

out, and accordingly the prints for securing the cores in their positions are added to the patterns of the flange, which itself is attached loosely to the pipe patterns. On the opposite side of the main pattern, prints are likewise fastened to receive the cores for the column sockets, Fig. 7, Plate XXXIV., and to the snugs *s s*, &c., to core out the holes in them.

A level bed in the sand upon the floor, of sufficient extent, is in the first place prepared for the pattern, which is then set down upon it and well bedded in its place, which is effected by blows given to it over the surface; the object being to form a complete impression of the under surface of the pattern. Sand is further laid in and rammed about the pattern on all sides, till it be brought up flush with the upper side, forming thereby the parting surface, on which the parting sand is strewed.

The next stage of the process is to lay the upper box or boxes over the pattern, and to fix them in their places by stakes of wood driven into the floor, which also guide us to replace them accurately when moved. If there is not a single box large enough to embrace the whole of the pattern, two or more smaller boxes are placed end to end over it, resting upon the sand external to the moulding, and answering the purpose of a single box. The ramming of these boxes is conducted in the usual manner, except at the end A.

Here it is evident that as the platform or cylinder plate is now on the under side of the pattern, the body of sand filling the space immediately above it to the level of the upper side must be lifted out to get the pattern removed. At the same time the weight of such a deep body of sand adhering to that in the overlying box, would overcome their cohesion, it would break away altogether. As the box is therefore incapable of carrying it with it, it becomes necessary to have this load of sand supported by independent means.

An iron frame is cast in open sand of the same form as the sunk space, but somewhat smaller, as allowance for the contraction of the casting, in the course of cooling, must be made to allow the plate to be withdrawn after the casting is executed. In cases where this precaution has not been sufficiently attended to, the jamming of the plate, enclosed on more than one side, has been the natural consequence, and sometimes the destruction of the casting by consequent

fracture. In the centre of the frame, a sufficient opening is allowed for the steam-ways. This frame is laid in the bottom of the recess, and as its under surface now faces the moulding, it must be enveloped on that side in the sand, to protect it from the immediate action of the metal afterwards poured into the mould. To assist its adhesion, the frame or plate is studded on the under side with numerous tooth-like projections, which are imbedded in the sand applied. Sand is now thrown in above the plate surrounding the steam-ways and well rammed, its parting surface being made flush with the upper edges of the pattern of the pipe-flange in the centre and of the contiguous body of sand forming the interior part of the moulding, their parting being just over the stiffening flange of the cylinder bottom. With this preparation the upper boxes, as already said, are set down and filled.

There are prepared six moulding gates to the moulding, and eight flow gates. Of the pouring gates or those by which the moulding is filled, two are placed along each side, about 4 feet distant, and two at the cylinder end of the moulding, while none are made at the other end. This unequal division is necessary on account of the heavier nature of the moulding at the cylinder end; the design of the whole being to have the moulding filled uniformly. The flow gates are distributed equally over the moulding. These will be again referred to.

Before lifting off the upper boxes, the pattern being now completely moulded, the latter is so far loosened in the sand, that this may not stick to it, and so spoil the operation. This is effected by gentle jolts communicated to the pattern by means of one or more pieces of rod iron, which have been screwed vertically into the pattern before finally ramming the sand in the upper box, or which merely enters into holes in the pattern. These rods being sufficiently long to pass out through the sand, when the box is filled, it is upon their upper extremities that the blows of the hammer are given, both vertically and horizontally, the force being regulated by the force and magnitude of the pattern. The rods, unscrewed if necessary, are now drawn straight out, and the upper box is in readiness to be lifted smoothly off.

After the box is removed, the plate and its overlying core of sand, as it may be termed, deposited at the recess of the cylinder

end of the pattern, are lifted out of their situations by arms rising through the core, carrying with them the pattern of the steam-ways, which is at liberty to go, for, as we have already noticed, it stands loose on the main pattern. That pattern itself is not in one piece; the flange, which is separate, is lifted off towards the upper side of the core, and the remainder of the pattern is drawn out by the under side. This is evidently the only mode of extracting the pattern, and shows the necessity in such cases of constructing patterns in twenty or more pieces to adapt them to the exigencies of the case.

The parts of the mould, in the neighbourhood of the pattern, must now, after the box is removed, be pierced with small holes executed by wires traversing the whole body of sand, with a view of rendering the moulding more porous, and of facilitating thereby the escape of the air and other gases; the mould is also watered along the edges to increase the coherence of the sand.

The pattern itself is taken out by lifting it in all its parts at once by pins secured into it at several places, so as to be raised in a truly vertical position. This manœuvre is performed by several men, who, while they lift the pattern with one hand, strike it gently and constantly with the other, thus continually checking any efforts made by the pattern to tear away the sand of the moulding, and now especially is this remedial application necessary, as the pattern is much more engaged in the lower moulding than in the upper, which indeed is the case in mouldings generally. Unavoidable degradations in one or other of the two parts of the mould do nevertheless occur, and these the workman repairs with damp sand by means of his trowel.

The moulding is next smoothed over the surface by the trowel, and a sprinkling of charcoal is then applied, and polished likewise by the trowel. It is, however, omitted for very large castings. Sometimes also, in order to avoid using too much charcoal, the surfaces are lightly dusted over with sand finely pulverized, through a bag. The moulding is now ready for the reception of the cores, the making and depositing of which claim the particular attention of the moulder, as the figure of the future casting will very much depend upon his accuracy in these respects.

Cores of several forms are necessary for the completion of the

moulding. There are, first, the cores for the column sockets, of which there are six; then the cores for the intermediate portions of the bed-plate, of which also there are six, there being two on each side between the socket cores, and one at each end; again two cores, for the holding down bolt-holes in the snugs at the bases of the columns, as well as for the holes that may be required for the bolting down of pedestals, &c., to the bed. For all these there are simple prints sprigged upon the pattern at the proper places, the impressions of which in the sand serve to hold the cores securely.

As we have already remarked about the beginning of this chapter, the cores must be made not only of the exact size and shape of the vacancies in a casting, whether partial or thorough, which they are intended to form; allowance must also be made on them for the core-prints when they are necessary. This allowance then is provided in the cores for the column sockets, for which there are prints on the under side of the pattern. These sockets go through the bed, and are square in the body and round at each end, as may be understood on referring to Figs. 6 and 7, Plate XXXIV., and to Fig. 2, Plate XXXV., which is a plan of the moulding showing the cores in their places. Fig. 3, Plate XXXV., is a longitudinal section of the moulding, taken through the steam ways. In both figures *f f f* is the sand of the floor, in which the moulding is formed, constituting the interior as well as the exterior of it; *b b*, &c., are the cores of the column sockets, seen in dotted lines in the section; *c*, *d* are the cores for the steam-ways which in Fig. 3 are seen projecting into the sand, and below filling the recesses made for them by the prints. Figs. 3, 4, and 5, Plate XXXIV., explain the shape of them. They are formed in boxes, which open in two for the purpose of extracting them. These, with all the other small cores, are dried upon hot plates, heated by stoves. At *a* and *e e*, &c., the cores are shown, forming the spaces in the moulding intended to be vacant. Near the under side of each, in Fig. 3, Plate XXXV., are shown the plates, indicated by dark lines, which sustain the cores. The whole, however, must be sustained by the bottom of the moulding, leaving a space of required thickness of the casting. This is effected by placing chaplets there; these are simply strips of sheet iron of small lengths but with double

knees, thus [. If the depth of these be just the thickness of the metal, then by placing several of them along the bed of the moulding, they support the cores placed over them, keeping the space clear for the metal; of course these chaplets will be imbedded in the casting, where they are allowed to remain. The double-knee cores at both ends of the moulding, it will be observed in Fig. 2, are put together, each in three pieces. In constructing the cores *e e*, &c., plain square bodies of sand of the dimensions of the interior of the casting are in the first place formed in boxes of the same size, including at the same time iron frames enveloped in the cores. Now, the small cores that are necessary to the oblong openings in the sides of the casting are simply attached in their proper positions to the sides of the main cores *e e*, &c. They are formed and fixed on by simply applying upon the larger core an open box of the form required, into which the sand is packed, thus causing it to adhere to the main core; when the box is filled, the sand is squared off by a straight edge flush with the surface of it. It is evident that if the box be lifted off, it leaves its core behind it. All the other smaller cores having been made and set in their places, the moulding is finally closed, the upper box being replaced, as seen in section *i i*, Fig. 3. This requires to be done cautiously and in a truly vertical direction, as it now receives the upper ends of the cores which project above the moulding, and also bears upon the other cores large and small, which do not require any additional security.

When convenient two or more gates are connected to one central reservoir, all built on the surface of the sand. Gates at considerable distances from others are usually supplied separately with iron from hand-ladles. The other gates that are connected are supplied by crane-ladles, which are conveyed by cranes from the cupola to the moulding. The ladles will be afterwards described. The flow-gates, while the metal is being formed, are plugged with clay-balls, to "keep down the air" in the moulding. These plugs are drawn out when the moulding is filled and the iron flows up. It is thus judged whether the casting is complete. The plugs must not be prematurely drawn, as by the too free egress given to the air, the bottom of the mould is apt to be disturbed by the air confined in the sand.

When the metal is poured, the "feeders" are immediately applied at the flow gates. These are rods of iron which are plunged into the liquid iron, and wrought up and down in it. By this agitative process the liquidity of the iron about the gates is of longer duration than otherwise maintained. It is therefore enabled to supply itself with additional iron from the flow gates, for it must be understood that in cooling down of large bodies of metal, the surface sets, while the interior is liquid; and therefore when the interior further contracts, it draws in the surface metal towards the centre, and if not fed as above described, the casting assumes a vesicular or honeycombed structure, which weakens it considerably. To avoid such a result as far as possible is the object of the agitation produced by the rod.

Amongst the great variety of work denominated green-sand moulding, much and varied contrivance is displayed in the structure of the moulds. In particular, the management of cores is a matter of very considerable importance, and the malformation of them is a prolific source of failure in the production of sound castings.

Cores are especially useful for forming vacancies in castings. Their forms may be long, and proportionally small in diameter, or winding or otherwise intricate; and, seeing that they are necessarily surrounded by the iron when cast, they ought to have as much as may be the qualities of firmness of substance and openness of pores. Cores, as has already been stated, are commonly composed of rock sand and sea sand. The former, having a proportion of clay in its composition to which it owes its powerful cohesiveness, when dried serves very well as a material for short cores that rest in the green sand at both ends, as open communication with it is thus afforded for the free escape of the air in the interstices of the cores. But when rock sand is used for cores of considerable height, which of course are surrounded on all sides by the iron, except the small imbedded portions at the extremities by which alone the air can escape, it requires to be moderated by the admixture of free sand as a counteractant to the clay. The clay communicates the necessary cohesiveness to the material of the core; the sand, on the contrary, being loose and open, renders it less binding and more porous. Free-sand alone is also employed in the making of confined cores, that they may afterwards be easily extracted, as the sand has

naturally no power of cohesion. Wanting cohesiveness, it must be tempered to a proper consistency by the addition of clay and water, yeast, or the refuse of the peasemeal used for light flat moulding purposes. In the use of the last material, it must be accurately proportioned to the sand with which it is mixed. The clay-water is, in ordinary cases, made use of as a cement, and the yeast only in very particular circumstances. For large compact masses of core, the common green sand may be used, as illustrated in both the last examples.

The longer cores are stiffened by iron wires and small rods, which are bent, if necessary, to the form of the cores. These rods are enveloped in the core in the progress of its formation, and are afterwards extracted from the casting. The cores of considerable length are pierced longitudinally by wires for the escape of the air; or, in cases in which this is impracticable on account of the bends or angles in the core, a piece of string is laid in the sand, alongside the stiffening wires, which is afterwards drawn out when the core is dry, leaving its perforation behind it.

With all these precautions for securing the strength of cores, and for the all-important purpose of letting off the air, blown holes do occur at times in castings, formed by the air thrown off from the cores into the iron.

When the bearings of cores at the extremities are considered unfit for steadying them, they are further sustained by steeples stuck into the sand at several places in their length. These are simply nails with broad flat heads, and several of them being set into the sand, and projecting above it just as much as the thickness of metal, the core is placed upon them and sustained steadily in its place; the steeples are, of course, buried in the casting, and the prints of them projecting outside are chipped off in the course of dressing it. Chaplets are also used to bear up cores having plane surfaces.

An excellent example of the use of free-sand cores is found in the construction of shell mouldings. The form we illustrate is now only used for mortar-shells, but was, until the introduction of the elongated projectiles required for rifled guns, employed for all descriptions of ordnance. It is simply a hollow sphere, Fig. 1, Plate XXXVI., of cast iron, having one small round hole as a

passage into the interior, termed the fuse-hole. The pattern of the shell is a plain globe, Fig. 2, of the same external diameter as itself, having a core-print *a* upon it, answering to the fuse-hole of the same diameter. Fig. 3 represents the core, the diameter of which is the same as that of the interior of the shell; it has a projection *a* to form the fuse-hole. The whole core is formed in a box which opens in two semispherical parts to allow the core to be extracted. A piece of double-twisted wire is enveloped in the core, projecting at the neck with a loop at the outer end. By this wire the core is to be held down. Fig. 4 is a sectional view of the moulding box, and the moulding, showing the core in its situation and the applications for holding it there by means of the wire, which passes through the bottom of the moulding and is locked on the under side. Two gates are also represented by which the metal is poured.

It is evident, then, that when the casting is formed, the fuse-hole is the only exit for the core-sand in the interior. The material of the core ought therefore to be easily friable, as it can be broken down only by external blows. Accordingly it is formed of free sand, so tempered with clay-water or other binding principle, as to acquire just such a tenacity as will enable it to bear the action of the metal. The fuse-hole core is made of rock sand, to enable it to bear the weight of the body of the core, and to withstand the strains to which it may be subjected. The surfaces of the core and exterior moulding are washed with a mixture of blackening and water, to communicate smooth interior and exterior surfaces to the shell. A pricker is sent into the heart of the core through the neck, forming by this means a passage for the escape of the air confined throughout its substance.

At Woolwich a modified form of plate-moulding was much used in casting the spherical shot and shell, in the following manner:—

A round hole is made in a flat planed plate of iron about two inches in thickness. A solid ball is passed through this aperture, of corresponding diameter with the hole, until exactly a half of it can be seen.

The lower flask is then put on to the plate, and the sand rammed in; a lever is then taken away, and the ball at once falls

by its own weight; the lower flask is removed, and the upper put on the plate. The same operation is gone through with this also.

The cores for filling up the centre of shell are very correctly made, and in very little time, at Woolwich. A lever opens and shuts the halves of the core-mould, so that the plan sometimes resorted to of shaking and knocking the core-mould is entirely done away with.

Shells of the modern form are moulded in a somewhat similar way, but in a flask resembling Fig. 1, Plate XXXI., care being taken to get good sound metal by pouring in the iron while liquid into small hand-ladles, each of which has arranged over it a receptacle into which all scum rises; when required, the filled ladles are removed from under these receptacles, and the clean metal poured from them into the moulds, the metal from the receptacles, amounting to at least 25 per cent. of that employed, being returned to the cupola.

Our next examples, Figs. 5 to 8, Plate XXXVI., are intended to illustrate generally the manner of constructing patterns in an exigency which frequently occurs, namely, when certain portions of a pattern enveloped in the sand, project horizontally beyond other parts which are above them. Were the pattern in such circumstances to be formed in one piece, it obviously could not be withdrawn from the sand, without breaking up the moulding at the parts referred to. This idea may be explained by Figs. 5 and 6 being respectively a cone and a sphere. Were these objects buried in the sand, as they are here shown, and then drawn out, the base of the cone would describe the space included in the vertical lines *o o*; and would also, of course, remove the overlying sand. A similar result would ensue with the sphere. The lower part of the sphere would be left as it is, while the upper part between the lines *o o* would be destroyed. The simple remedy for these cases would be to invert the position of Fig. 5, as shown in Fig. 7, and to mould the sphere, Fig. 6, so as to have its largest horizontal diameter at the surface of the sand, Fig. 8. While the under half could thus be moulded in the under box, the other half would be rammed up in the upper box. As in these, so in all other instances, patterns, or parts of patterns, to be capable of being moulded in sand, must

in their general outline taper from the surface of the sand downward. For this reason, such parts of the surface of a pattern as may be intended to be vertical, when it is being made, are never truly so. A slight tapering inclination is given them, that they may leave the sand more readily.

A variety of other peculiar circumstances, however, frequently require special modes of management. For example, a common sheave requires a particular and an elegant process to execute the moulding of it. Fig. 1, Plate XXXVII., is a diametrical section of one. The circumference, it will be observed, is grooved out semi-circularly at *a*, and a hole *o* is made through the centre. The object is now, to mould the pattern in such a manner as that the portion of sand forming the groove *a a* may be left in its place when the pattern is drawn out. The pattern, Fig. 2, must be formed in two halves, separated by the plane *a′* passing through the centre of the groove. These halves are prevented from shifting by pins *n n*, or this may also be effected by a button on the centre of the one, fitting a recess in the other, as in the figure. There are also prints at *o o*, for supporting the core.

Fig. 3 represents, in section, the moulding of the pulley, *d d* and *b b* are the boxes. The pattern is first bedded in the lower box, and a parting *c c′* formed from the under rim to the edge of the box. The ring of sand *c c′ e* is, in the next place, rammed about the pattern, filling the groove, and its upper parting surface *e c* is brought from the upper rim. Again, the upper box is placed on the other, and also filled.

The ramming being now completed, and the gate-pin set, the box *d d* is lifted off, carrying with it the impression of the upper side of the pattern. The upper half of the pattern being free, is lifted away, and the box *d d* replaced. The whole is now inverted, and the box *b b* is lifted off, thus permitting the remaining part of the pattern to be removed, which being done, and the moulding blackened and smoothed, and the core *o* set in, the box is replaced, and the two are finally reinverted. It will be observed that the annular core *c d e* is never lifted from its situation during the process, and when the two boxes are linked together, it is wedged in on every side, and thus all possibility of shifting is removed.

When there may not be facilities for turning the patterns of pulleys of large diameter, the grooves are cored out in the moulding. For this purpose a core-print running round the pattern is provided in the making, as sketched in Fig. 4, which is a section of a rim of a wheel supposed to be made with arms. The print is indicated by the dotted lines, and a core of the sectional form *f g h* is constructed in a core-box for the purpose. As there are only two boxes for the moulding, the pattern is mostly imbedded in the under one, the parting being formed on a level with the core-print at *f*. It is not necessary that the core be all one piece; it may, for convenience, be formed in several segments.

We shall now select a fluted pipe as an example of another variety of adaptation. Fig. 1, Plate XXXVIII., is a transverse sectional view of a pipe, which may be supposed to be about five inches in diameter, six feet long, and three-sixteenths of an inch thick. It will be observed that the core or interior of the pipe follows in form the exterior surface, the object being to make the pipe as light as possible, otherwise a round core might have been substituted.

To determine then the method of casting this pipe;—It is to be noted, in the first place, as a general rule, all cylindrical bodies of any considerable length are moulded in two boxes, one-half in each. Agreeably to this, the patterns are usually divided longitudinally in two halves. Referring to Fig. 2, which is a cross-section of the pipe pattern, the line *a a* represents the main division which would suffice for a pattern having a plain exterior. For this column, however, deep as the flutes are, subdivisions are necessary, to render the moulding of it practicable. For it is easily seen that the angles *b b b b* immediately adjoining the parting *a a* overhang the bottom of the hollow between *a* and *b*, and therefore if the patterns were drawn vertically out of the sand, they must break away the intervening portions of sand that occupy these hollows. Such parts of the pattern require to be removed laterally, and for this purpose, each half is made in three divisions, as represented at *c c c*, dovetailed to one another, allowing the smaller pieces to slide off the larger. Fig. 3 represents the core-box for the pipe. It is, like the pattern, parted in two at *a a*. On the top of the upper half a loose piece *b*, the length of the box, is provided, which being removed, the sand

for the core may be introduced by the opening; *o* is the core-bar, which runs the whole length for the purpose of stiffening the core.

The pattern having been moulded in the usual manner, one-half in each box, so that the plane *a a*, Fig. 2, coincides with the parting of the sand, the middle piece of each half is first drawn out, when the smaller pieces may next be removed laterally to make way for the core.

On this principle of construction in similar circumstances, patterns are generally made. Fitting strips, for example, when applied to the vertical face of a pattern, below the surface of the moulding, are attached to it by sliding dovetails. Core-prints are very often placed in such circumstances. In Fig. 4, Plate XXXVIII., which is the pattern of a flanged plate, *i* and *l* are two core-prints, which, instead of being dovetailed to the pattern, are carried quite down to the plate, which is moulded in an inverted position; these continuations clear the way for the prints themselves, which would otherwise break the moulding. After the cores are introduced, these temporary vacancies are filled up with the aid of smooth strips of wood, and the figure of the moulding restored. In general, core-prints on vertical faces of patterns, are carried up to the parting surface with the view of making their own passage, which is afterwards closed over the core.

Take for our next example a panelled octagon column or post. It presents a more complicated structure than the pipe, Fig. 1, and to render it workable in the sand, the panels are, each by itself, made separable from the body of the pattern, being attached to it by screw-nails, which are driven from the inside. The pattern is divided into two principal halves. When it is moulded, the panels, of which there are four to each half, are fixed on. When the parts of the box are separated, exposing each a half interior of the pattern, the screws are returned and withdrawn, thus leaving the frame of the pattern at liberty from the panels. It is next lifted out, and these being disengaged from the sand by tapping, are likewise taken out in order. In this way, a complete external moulding of the column is formed. The core, constructed upon a stout bar, is next inserted and the box closed upon it.

Of the use of plates in moulding, an example has already been given in the account of the moulding of an engine bed-plate. A

different application will now be described in relation to the moulding of a lathe-bed. Fig. 5, Plate XXXVII., is an end view of the bed; *a a* are the upper sliding surfaces overhanging the sides; these are connected and stiffened at several parts by deep flanges joining them. The surfaces *a a*, as they are the most important parts of the bed, are, according to the general rule, moulded undermost, the object being to secure a sound structure at these parts, free from blown holes and impurities, which collect, more or less, towards the upper side of every casting. Fig. 6 is a section of the pattern and moulding. The parts *a a* are simply attached by loose pins to the rest of the pattern. The first step is to bed the pattern, in an inverted position, thoroughly on the floor, which is levelled and smoothed all about it. Plates *b b*, extending the whole length of the pattern, are set along both sides of it, an inch or so apart, to support the sand exterior to the pattern. A series of small rods, either of wood or iron, is placed on each plate. These rods overhang it on the side next the pattern, from which, however, they must be at some distance. In this way the rods form a projecting platform, by which the sand that would overhang the plate is sustained. If of wood, the rods are dipped in clay-water, that they may adhere to the sand. The moulding is made up with sand, flush with the pattern within and without. The parting is formed and covered in by the upper box as usual, which being lifted off, and the pattern having been loosened, it is drawn out, leaving the loose pieces *a a* imbedded in the three masses of sand *n n o*. The masses *n n* resting on the plates are raised and moved aside by handles which are cast upon the plates and project upwards. The pieces *a a* being thus relieved are edged out from below the sand *o*, and removed. *n n* are replaced as before, guided by conical projections from the plates, and the moulding is covered by the upper box.

Plates are also employed in the moulds of bevel-wheel patterns for lifting the bodies of sand sunk between the arms. Frequently, too, in miscellaneous cases, where considerable depths of sand occur in the upper part of the mould, slips of wood are planted vertically in the masses, reaching upwards between the ribs of the upper box, their object being to bind the whole body of sand the more firmly together.

The next branch of the subject which falls under consideration is the manufacture of works in dry sand, usually called dry-sand moulding. This department embraces, generally, the manufacture of pipes, columns, shafts, and other long bodies of a cylindrical form, or approaching to it; the first is most important, for cast-iron pipes are extensively used to convey water, gas, or air for various technical purposes. Dried or baked sand, as was formerly stated, consists of loam, called pit sand, that has already been used in structures of loam work, mixed with fresh sand. Dry sand acquires a very firm and open consistence by the expulsion of its humidity by heat, and it is found to be much better adapted to the purposes above mentioned than green sand.

The mechanical part of the process of moulding in dry sand is the same as in the case of green-sand work. In general, no coal-powder is mixed with this sand. When the mouldings are finished they are transferred to drying stoves, in which they are exposed twelve hours or upwards, as occasion requires, to the action of a strong heat till their humidity is banished. The experience of the moulder must be his guide, in so mixing the materials at his disposal, as to produce the most accurate form of the mould when finished, which shall also be sufficiently porous. Such moulds permit a readier egress for the gases generated by the casting than green sand; generally, also, the castings turned out are less vesicular, and smoother upon the surface.

When the castings are large, and especially if they are tall, the hydrostatic pressure of the metal upon the sides of the mould is counteracted both by firmness of the sand and by the wedge-shape form of the boxes. To aid the resistance, the sides are feathered along the outside, affording additional abutting surface for the sand.

Fig. 9, Plate XXXVIII., is a side view of one-half of a moulding box for pipes, the other half, Fig. 8, shown in plan, being an exact counterpart. Fig. 5 is a cross-section showing the parallel sides. Fig. 6 is a similar section of a wedge-shaped box for heavier castings. It is formed with flanges along the sides, which meet those of the other box. By means of these flanges the two halves are bound together by glands. Fig. 7 is a cross-section of a flanged rib. A pair of swivels is attached to the ends of each box, by which they are raised and inverted as occasion requires. Another pair is

usually fixed on the middle of the sides, upon which, when the boxes are hung, they may turn in a direction perpendicular to the preceding, that they may be set vertically at their destined position, which is commonly in a pit dug to receive them.

Pipe moulds are always either set upright on one end, or laid in a position very considerably inclined, on a bed of sand prepared for the boxes at an angle of 30° or 40°. When practicable, the larger sizes of pipe moulds are placed in a vertical position, as well as all other comparatively tall articles; the general object being to raise all the slag that collects on the surface of the iron, while being poured, clear of the cast into the gate-way, securing thereby soundness to the cast. It is evident that were pipes, for example, cast horizontally, the metal, at any given period in the running, would expose a large horizontal surface, which is unfavourable to the soundness of the casting, and impurities, besides, would infallibly lodge in the upper portion of the mould. Both of these objections are removed by setting the mould in an inclined or a vertical position.

In proceeding to describe the method of forming moulds, it will be necessary, in the first place, to describe the construction and the formation of the cores. In the constructing of pipe moulds, as well as the moulds of all other large hollow articles, it is necessary that the core be made both rigid and porous; these conditions are obviously necessary, when it is remembered that the least flexibility in the core must alter the thickness of the casting; besides that the core, being itself so much confined externally by the liquid metal when poured, the ends alone serving as channels of escape for the interior air, must offer within itself facilities for the escape of the gases generated. Both of these objects are accomplished by employing a tube of iron, forming the centre of the core, and perforated at regular distances for the escape of the air. For the smallest sizes of cores common gas-pipes are used, with holes drilled in them at about nine inches distance, on alternate sides. Wrought iron tubes of a larger size are employed for larger pipes; and for the largest sizes cast-iron pipes are adopted, with rows of oblong holes cut at equal distances for ventilation. These cast-iron core-bars, the general appellation for all the varieties enumerated, have wrought-iron double knees, fitted and bolted to their extremities, for

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the purpose of sustaining journals or bearings, upon which they may be turned on their own axes. The hollow ends of the wrought-iron pipes are formed square to receive a winch, by which they also may be made to turn upon themselves, the use of which operation will speedily appear.

Again, a core-bar for a pipe of any given inside diameter is selected two or three inches less in diameter, with the view of providing for hay-rope, and loam, by which the core is made up to the necessary thickness. The loam, which forms the external coat of the core, is made as open as practicable by augmenting the usual proportion of sharp sand in its composition. The hay, also, which is simply twisted into ropes to facilitate its application to the core, fulfils the important office of a conducting medium for the air forced through the loam, leading it from all parts of the surface to the vent-holes in the core-bar. The method of applying the hay and the loam is simple. The core-bar is rested by its pivots on two iron tresses, the upper edges of which are formed with corresponding semicircular or triangular dentations, to receive the pivots. Thus placed, the core-bar is caused to revolve by a crank-handle applied at one extremity, during which operation the rope is led on regularly along the bar from end to end, and fastened there. It must be tightly done, as any slackness in the rope will permit it to yield when subjected to the pressure of the iron, which has the effect, at least, of altering the form of the pipe, if, as in some cases, it does not break up the core and spoil the casting. Before finishing the core with loam, the hay receives a slight coating of it all over, as a cement to smooth down the surface. This being dried, for the succeeding application of the loam, a loam board is necessary. This is a board of sufficient length to rest upon the tresses which support the core. Along this board is laid the loam intended to form the core. The edge of the board is cut exactly to the form of the core, being indeed a half skeleton reversed. This board being set alongside the bar, and weighted down at the extremities, at a distance of the half diameter of the pipe from the centre, it is evident, that as the core-bar revolves, and the loam is pushed over upon it, there will ultimately be formed a coating of loam completely enveloping the coat of hay, which shall also possess the figure of the core.

In this manner the core is formed. The figures in Plate

XXXIX. illustrate the process. Fig. 2 is a longitudinal section of a pipe, in which the exterior and interior outlines are represented. The dotted lines at each end indicate the additions necessary in the pattern as core-prints. Accordingly Fig. 3 represents the core as formed upon the bar before described, the core being prolonged to be supported in its bearings formed by the pattern, though it matters not if it should be longer than necessary. Fig. 5 represents the core-bar with its pivots at the ends, and the vent-holes scattered over its surface. Fig. 4 shows the loam board employed in constructing the core of the pipe. It will be observed to follow the outline of the core. Fig. 1, in like manner, represents the loam board that would be required to form the pipe itself, Fig. 2, were there no wood pattern of it. In such a case an additional coat of loam is run by means of it upon the core. In this way it is evident a loam pattern is at once formed. In setting the board, the parts *a a*, Fig. 1, will apply to the same parts *a a*, Fig. 3, which, in so far, serve for a gauge. The misplacing of them exactly opposite each other is to be guarded against, as there is not the same security for their being correctly placed. Before receiving, however, the additional thickness, the core must be washed over the surface with charcoal and water, that the thickness may be easily separable afterwards, and also thoroughly dried in the stove. In the mean time, having finished and dried the loam pattern, it receives in like manner a wash with charcoal water, and is ready to be moulded. This being done in the usual manner, the thickness is peeled off, and the naked core replaced in the mould. To aid the stiffness of the core, steeples are planted here and there over the surface of the mould, as explained, which resist any undue tendency of the core on one side or another. Fig. 6 is a cross-section of the body of the core. There are three concentric plies, the inmost, which is the core-bar, with several vent-holes in section, and the cross knee at the end; the next the hay, and the external coat is the loam. Fig. 9 is a sketch of one of the iron tresses used in the work.

All wood patterns of pipes are constructed in two halves, which have two or more pins in the one entering corresponding recesses in the other, to prevent their shifting when put together and moulded. In proceeding to mould a pipe, a laying-down board is

usually employed, which is simply a straight piece of wood as long and as wide as the moulding box. Upon this board one half of the pipe is laid with the flat side down, the box is placed over it, and rammed; the whole is inverted and the board lifted off. The remaining half of the pipe is set upon the imbedded half, and the upper box over it, and linked to the under one; the upper box being rammed, the patterns are loosened, as we have in other parts described, and longitudinally also by blows upon the ends. The boxes being parted, the patterns removed, and the moulding black-washed with blackening, the core is set in and the box closed. Small pipes, when there are several to be cast, are usually moulded in pairs in one box, when green sand is employed as a moulding material. The metal is poured in at one entrance, which branches to each moulding; shortly after which streams of aqueous vapour mixed with hydrogen and other gases, arising from the imperfect combustion of the charcoal and hay, are expelled from the extremities of the core-bars, sometimes resolving themselves into luminous jets. Soon after the metal is poured, the castings are turned out to cool; after which the core-bars are drawn from them, which is a comparatively easy task, as the hay has been for the most part consumed, and of course occupies less bulk. Long small rods of iron are next introduced, with scrapers formed on the ends of them, and they are drawn from end to end to clear the interior of the pipe of the remains of the core.

In the moulding of the various lengths of pipe that are required for use, one pattern is made to answer. Pipe patterns are generally made nine feet long, of which an appropriate number of lengths are cast when more than nine feet of piping is required. But shorter lengths also are frequently wanted, when, of course, the full length of the pattern would not be proper. The moulding, therefore, is cut to the required length; in technical language, the pattern is cut in the sand. In such a case some preparation is necessary to form a new bearing for the core. For this purpose, two semicircular pieces of wood, of the diameters of the mould and the core respectively, are sprigged together end to end, as in Fig. 7; and it is obvious that by placing the larger piece in the mould in each box at corresponding parts, and ramming fresh sand about the former, the bearing will be formed. In like manner, if the piece of

pipe terminate in a flange, the flange having been moulded in its place, a half flange of the same dimensions, with a half core-print on it, as at Fig. 8, is set into the mould, and the bearings for the core made up. Small perpendicular branches required to be made upon pipes are cast either horizontally or vertically, as best may suit the form of the box. In the latter case, the branch pattern is set loose upon the pipe, projecting upwards between the ribs of the box, and, having been moulded, it is drawn out, and its core set in upon the pipe-core, and the whole covered in.

Besides straight pipes, others have often to be cast of different forms, requiring peculiar treatment. In arrangements of pipe works there is usually a number of knees or bends in their construction. These bends are ordinarily cast separate from the straight portions of pipe, having facets upon them by which they may be afterwards joined to the pipes. Fig. 10 is a longitudinal section of a square knee in a line of pipes, showing the method of junction by spigot and facet. The term spigot, it may be as well to observe, is applied to the small semicircular ring upon the plain end of a pipe, as may be seen in Fig. 2; facet denominates the cup mouth on the other end for receiving the spigot. There are usually patterns and core-boxes for pipe bends of the usual square knee shape, in which case they are moulded in green sand. In the absence of patterns, however, for these and for other varieties of short piping, they are swept up in loam, the core within the "thickness."

In this process, the first point is to have a level iron plate set, upon which the work is to be done. Like patterns, the loam work is to be formed in two halves. The cores are executed in the first place, and, when dried, the thicknesses forming the exterior of the casting are next laid on. Fig. 12 represents the gauge usually employed in forming small pipe work. As already said, the work is done in separate halves, for which purpose semicircular cuts are made in the gauge, of which one is smaller than the other, being respectively the measures of the core, and of the additional thickness.

For example, suppose a bend, Fig. 10, is to be constructed, a small square rod of iron is bent to the form of the knee, against and along the side of which the gauge is moved. A quantity of loam being laid on the plate in the line of the pipe to be formed,

the gauge in its progress fashioning the loam to its own form. When the two half cores are in this manner swept up, they are well dried and blackwashed, after which the gauge is inverted, and additional loam being laid on for thickness, it is likewise shaped to the form of the pipe. The junction of the body of the pipe and facet, which are of different diameters, and of course require different sweeps, is scraped out by a file when the loam is dried; the head on the end of the facet is either formed by a pattern applied to the moulding, or cut out of the cope.

The loam pattern being thus completed in two halves, dried and blackened, it is bound together at two or three places by iron wire, and bedded half into a sufficient quantity of old loam mixed with water and laid over the iron plate. The boundary of the loam is built up with fragments of cake loam. The bed being smoothed off on each side and dried, a layer of the same watered loam is applied to cover in the upper half of the pattern. As this upper layer has afterwards to be lifted whole, it requires to be strengthened by the addition of irons. With this view, pieces of rod iron, accommodated to the form of the moulding, are laid on among the wet loam transversely and longitudinally, and bound together by wires at the angles, constituting a kind of skeleton framework, Fig. 13, for the cope, as it is termed, or upper structure. The irons are then covered in with old loam, which is smoothed over them, and the whole is for the last time thoroughly dried.

The building of the work being now completed, the next step is to undo it to clear out the thickness. The cope is lifted off carefully, leaving the rest of the work behind it, and this complete separation of the parts is one object for which the blackening and charcoal water is applied. In the same way the pattern is lifted out from the bed of the moulding. The thickness is easily broken off the core, leaving the latter entire; the halves of which are next bound by wire, and replaced in the mould, stayed by bearings at the ends, and by steeples intermediately. The cope is replaced, guided to its former situation by intentional irregularities on the junction surface, and is bound by wires laying hold of the skeleton, to the under plate.

The gate is formed in the usual manner by a pin stuck in the cope while being formed.

For some small pipes, such as bends, which are uniformly circular, circular iron plates are frequently made to the same centre on both sides, so that when the cores are swept up on them, they lie concentric with each other. The edges of the plate will therefore serve for guides in the making of the core. For this purpose the gauges are made as in Fig. 11, having a piece of wood nailed on and projecting downwards. By sliding this gauge along the interior or exterior edge, as it may be adapted for them, the pipe is formed as before. The manner of moulding and casting columns of every variety, and other long hollow work, is essentially the same as that now described for pipes; it is unnecessary to extend further our details upon these articles.

Cast iron, bronze, or steel guns are moulded in the way just described. Patterns of wood are not often employed, as it is worth while to construct iron patterns, which, when turned and polished in the lathe, always preserve their figure and turn out good moulds.

As it is desirable to have these iron patterns as light as possible, consistent with the straining to which they may be subjected, they are made hollow throughout. It is then the business of the moulder, in the first place, to form a hay-and-loam pattern in a manner similar to that in which pipe patterns of loam are made.

As it is of great importance to secure solidity to gun-castings, they are made without bore, and with an additional length on the muzzle end, which is provided for in the pattern. When the mould is formed and set on end in readiness for being cast, the metal is poured into it, slowly at first, increasing in flow as the mould is filled to the top, which is left open. Into this additional portion, then, all the sullage rises that is collected during the course of the pouring, leaving the body of the gun-casting generally in a pure state. The moulding sand adheres very firmly to the casting, and requires to be knocked off by hammer and chisel afterwards in the course of dressing.

Guns were formerly nearly all cast, and their manufacture formed a large feature in the moulding business; the introduction of built-up wrought-iron guns has, however, changed all this, and ordnance is not cast as it used to be.

It is important to observe that at the time when the casting is poured, all the strength of the core is required to resist the weight

of the fluid metal, but as soon as it becomes set, the conditions are reversed, and the resistance must be removed, or lessened, so as to allow the contraction of the metal in cooling to proceed without restraint.

In the case of a large cylinder, for instance, a few hours after pouring, as much of the core as can be reached is brought away, so that the remainder may offer less resistance to the metal. This operation is much facilitated if the core is supported by strong diagonal stays and ties, which can be easily and quickly knocked out of their positions, as the heat is so great that it is impossible for the men to remain long at work. This removal of the core must, however, be performed with great caution, as if an entire core were removed too quickly, the evil to be guarded against would in fact be increased by the sudden cooling.

Loam moulding, the last branch of the art, as it has been treated in these pages, now falls to be discussed. As already described, the peculiar functions of the loam moulder is to construct loam patterns and mouldings of certain cast-iron work, by which the mould may be formed without incurring the expense of the construction of a wood pattern for that purpose. In numerous cases the loam moulder also constructs moulds for which wood patterns could not be provided. The economical employment, however, of loam as a substitute for wood patterns and sand, is restricted, in general, to the manufacture of the more regularly shaped work of the foundry. Every variety of circular bodies may be done in loam; large square vessels, too, are done by the same process.

Every piece of loam moulding, of any considerable extent, is a regularly built structure, being composed of bricks, arranged in layers, and bedded in loam, in which they are also entirely enveloped, particularly on those sides contiguous to the mould. The composition of loam demands strict attention, varied, as it requires to be, suitably to the numerous applications of loam. Two indispensable qualities are those of firmness and porosity. The first is evidently necessary, considering the very great hydrostatic pressure to which, in large castings, mouldings are subjected, while the iron is liquid, And again, the copious effusion of gases from the mould, arising from the action of the heat of the cast, renders it absolutely

necessary to provide for their escape through the material of the mould. This is provided for in the porosity of the mass, which must therefore be in such a degree, as to offer a transit sufficiently free to the gases evolved, while the mould is impervious to the metallic fluid.

To fulfil these conditions, the materials of loam are principally clay and clean sharp sand. These elements are opposed in their nature, and operate as counteractives. The clay is the binding element from which the loam derives its firmness; the sand intermixed with it modulates its closeness, and renders the loam open in the grain. Thus both these elements are essential in the composition of the substance. Cow-hair also, obtained from hides of cattle by tanning, is mixed in loam; it answers two purposes. In the first instance, while the raw loam is being moulded into the form desired, the hair assists the tenacity of the parts of the loam, which is often largely charged with water. Again, when loam work is baked in the stove, which for cores is raised to the greatest attainable temperature, the hair is burnt out of the loam, and, of course, leaves its own empty track. The mould is thus perforated in all directions throughout by these artificial sinuosities; and in this way the openness of the mould is very much increased. Millseed, saw-dust, horse-hair and straw, especially the last, are also extensively used in the formation of loam cores. It ought to be understood that loam cores must be completely dried and burnt before they can be serviceable; the object being to anticipate the work of the hot iron with which they must afterwards come into contact, by expelling completely their humidity, and the occasional gases originated by the burning of their combustible matter. Were this precaution not taken, particularly for cores much confined, they would be broken up by the sudden generation of confined air, which could not escape as suddenly. It may be as well to state here that the general results of the action of melted iron on the mould are carbonic acid and oxide and carburetted hydrogen. In the first place, the carbon constituting the blackening used in all moulds, and the coal-powder in green-sand moulds, seizes and combines with the oxygen of the aqueous particles in the neighbourhood, forming a mixture of carbonic acid and oxide; the hydrogen of the water thus let loose combines with another portion of carbon,

producing carburetted hydrogen, which, with the carbonic oxide, burns with a bluish-yellow flame on coming into contact with the external atmosphere.

For all varieties of circular bodies, or such as may be described round one axis, a wooden board is cut on one edge to the exact form of the object, being, in fact, a half skeleton of its outline. If the body be cored out, a board must also be provided, cut to the form of the interior space. A central spindle is erected, which is to represent the centre of the body to be moulded; to this spindle one or more arms are screwed, provided with glands, by which the loam board, as it is termed, is set at the proper radial distance from the centre, and firmly fixed to it. The whole being in this condition turned round the centre, it is obvious that the figure of the body will be described. With this general idea we shall proceed to particular description.

Large iron pans used in soda, sugar, and other chemical manufactures, are amongst the most familiar examples of loam moulding, and as they are in themselves instructive specimens of this kind of work, they shall be selected as our first illustration.

Fig. 1, Plate XLV., is a general view of a common shaped sugar pan. The portion *a b*, constituting the pan, is a simple spherical cone, and *b c* is the brim.

The pan is moulded and cast in an inverted position, similar to the Irish pots, already described. In the first place, then, a cast-iron ring *a′ a′*, Fig. 6, is levelled upon blocks, which raise it off the floor of the foundry, and is placed concentric with a spindle *b′*, which stands upright, being placed at the under end in a cast-iron step sunk in the floor, and stayed at the upper end in a bush on the end of a bracket *c′*, which projects from the wall, and turns horizontally upon pivots. The spindle thus stayed is free to move round in both directions. To prevent the bracket from moving on its pivots, it is linked by the extremity to the wall. A forked arm *d* is fixed upon the spindle by an eye at one end, tightened by a pinching screw. Between the branches of this arm the loam board *e* is set, and fixed by glands in the required position.

Fig. 2 represents the outlines to which loam boards are cut; *a b c* is the figure of the interior surface of the pan, *b d* being the axis. A board *e* is, in the first place, cut to the semi-outline of the

interior; and further, has an additional check o, which turns out a corresponding knee in the mould, the object of which is to support the overlying part of the mould on its horizontal surface, and to act afterwards, by its vertical surface, as a guide in replacing the mould. Another board f, is in the same way cut to the external figure of the pan, with a check precisely similar to the one in the board e, and thus it will act as a guide in setting the second board.

Fig. 3 is a vertical section of the work in the first stage of its progress. Upon the ring $a'\ a'$ a kind of dome is, in the first place, built of bricks and loam, generally some four inches thick. The moulder is guided in the construction of this dome by the interior loam board, sustained by the spindle. The external surface ought to be everywhere about two inches distant from the surface described by the board $e\ e$. Before building up the dome to the crown, coals are placed in the floor within it, which are afterwards kindled for drying the work. The crown is then nearly completed, leaving only a small space round the spindle, to allow of ventilation when the combustion within is going on. By this aperture the moulder is enabled to manage his fire, so as to to check its progress, if necessary. The consumption ought to be very slow, so as to allow of the heat taking effect upon the entire mass.

Over the brick dome a pasty layer of core loam $o'\ o'$ is applied; for it is in fact the core that is now being formed. The surface is finished off by a smoothing coating of wet loam, the redundancies all over the surface being swept off by the board in its revolution. Upon this surface the inside of the pan is cast. The fire is now kindled, and as the surface of the mould becomes dry, it is painted over by a brush with a mixture of water and charcoal powder, with a little clay additional. This operation prevents adhesion between the surfaces of the core and the coat of loam applied to it.

The core board having been removed, it is replaced, as in Fig. 4, by the thickness board f, Fig. 2, of which the edge describes the external surface of the pan, and, as already remarked, simply rubs against the knee formed round the base of the core. Another layer of loam $a''\ a''$ is then spread over the core, and is rounded off properly by the board similarly to the core itself. When well dried

it is blackwashed, as was done to the core. The upright spindle is now removed, leaving the small vent-hole through which it passed to promote the complete combustion of the coal. There is now laid horizontally upon the ears of the platform *d' d'*, Fig. 4, another platform similar to the former, but sufficiently large to pass over the moulding already executed. A new layer of loam, two inches thick, is laid over the thickness and smoothed by hand. Then, upon the second platform, a brick vault is constructed as before, of which the inner surface applies to the new coat of loam. This contracts a strong adherence with the bricks, which absorb a part of its moisture, while the coat of paint prevents its adhesion to the thickness. The brick and loam covering are named the cope.

The structure is thus completed so far as the formation of it is concerned. The whole mass must now be thoroughly baked by the continuance of the fire. Stoves are preferred to internal fires where they are large enough to receive the work. The intense heat, however, necessary to the preparation of many cores, placed in confined parts of moulds, is not essential to such cores as the above-described, where there is so free a space within it for the escape of air.

Cast-iron bars may be substituted for the brick forming the cope. These "irons" must, of course, have the curved form of the dome to which they apply, being arranged so as to converge towards the crown. They are simply run off in open sand, when required, with snugs cast upon them, by which the cope may be lifted off. They are bedded in the external coat of loam, which is smoothed over them, and bound together by wires and bands of hoop-iron.

The next step is to lift off the cope, which is done with the assistance of a crane. This being effected, access is had to the interior, and the thickness is easily broken away without any injury to the mould; this thickness forming, in fact, the pattern of the pan, it is evident that when the cope is replaced exactly, which it may be by the guidance of the knee before described, there will be a space within to be filled with metal; this space is the true form of the pan. Before replacing the cope, the vent aperture in the core is filled up and smoothed over, though the one in the cope is left open to serve afterwards as a gate for the reception of the metal.

The cope being reset, and clamped firmly to the core by double

knees and wedges, embracing the rings, the whole is removed to the pit in which it is sunk, and rammed up tightly with sand by iron rammers, which are managed by half-a-dozen or more men, who walk regularly round the moulds, keeping time with their rammers, and dealing heavy and light blows alternately, while one or two workmen above shovel in additional sand as required. Fig. 5 is a vertical section of the pit, showing the manner in which it is arranged. A space sufficiently deep is first cleared out, and across the bottom a passage $a^* a^*$ is cut, and overlaid with plates, having only an open part in the centre which connects it with the interior space in the mould. Two pipes *c l*, *c l* are next laid in against the sides of the pit, communicating with the channel $a^* a^*$. When the mould is lowered into its position in the centre as indicated, and the sand rammed about it in the way already described, an oblong shallow trough-like cavity *e* is formed in the surface of the sand, one end of which opens into the gate-hole of the mould, which is closed by a pin while the ramming is proceeded with.

The channel $a^* a^*$ and the pipes fulfil the very important purpose of venting the air confined in the hollow space, together with what is forced through the substance of the core when the metal is poured. Now, as a large quantity of inflammable gas is driven off, its union with the atmospheric air in the chambers below forms a dangerous explosive mixture, which, rushing out of the openings *l l*, might be inflamed by accident, and, if not prevented, would blow up the whole work with irresistible force. To prevent such an occurrence, the vents are stopped at *l l* with plugs of straw or mill waste, or simply covered with pieces of fine wire sieve, the gas passing through these before being exposed to any accidental inflammation, security from explosion is rendered certain, as flame cannot pass through their interstices. The principle alluded to is familiar to all, as exemplified in the Davy lamp, in which the flame in the interior is intercepted by a wire-gauze medium.

When the metal has been poured, and has well set, the casting is cleared out as quickly as possible, as, on account of the contraction it undergoes, it is apt to gain upon the core. Confined cores are always broken up as soon after casting as may be, especially when their form is calculated to resist great compressive force.

When the object to be moulded presents more complicated forms than the one now chosen for the sake of illustration, it is always by analogous processes that the workmen constructs his loam moulds, but his sagacity must hit upon modes of executing many things which at first sight appear to be scarcely possible. Thus when the forms of the interior and exterior do not permit the moulds to be separated in two pieces, it is divided into several, which are nicely fitted with adjusting pins. More than two cast-iron rings or platforms are sometimes necessary. When ovals or angular surfaces are to be traced instead of those of revolution, no upright spindle is employed, but wooden or cast-iron guides made on purpose, along which the pattern cut-out board is slid according to the drawing of the piece. In addition to brick work, iron wires or claws are often interspersed through the work to increase its adhesion. When parts of a mould are higher than that portion immediately under the gate, flow-gates are usually adapted to such parts, by which they may be relieved of the impurities that would be apt to lodge there. Such a case is that of a flattish bottomed boiler, of which the bottom is hollow externally.

Our second example of loam mouldings shall be that of a large steam cylinder. Fig. 1, Plate XLVI., is a side elevation of one; Fig. 2 is a sectional elevation; Fig. 3 represents a horizontal section taken through the centre of the exhaust steam passage; *a a* are the steam passages to the cylinder, *b b* the exhaust passage, all uniting in the face *x*; *d* is the outlet from the passage *b b*.

It is to be noted that the body of the cylinder is round, while the base or bottom flange *e e* is square, and the face *f x f*, containing the steam-ways, is supplementary to the main part, as also the stiffening feathers for strengthening the base. For these parts, then, patterns in wood are made adapted to fit the loam work. Figs. 4 and 5 are front and side views of the pattern of the part *f f*, having core-prints *c c c*, for the usual purpose of steadying the cores.

As the upper flange of a cylinder, such as the one now described, is generally smaller than the under one, and more exposed to view, the cylinder is usually cast in an inverted position to have the former flange solid. According to the method now most generally adopted for moulding cylinders, the cope or external out-

line is formed in the first place by an interier loam board cut to the form on the outer edge. Thus, the cope is first constructed, after which it is removed, and on the same centre, the core or interior outline is formed by an external loam board cut on the inner edge If the cope be replaced concentric with the core, they will include between them a vacant space, being the exact figure of the cylinder. Fig. 6, Plate XLVI., represents the two first stages of the work; the core-ring $a' a'$, seen in section, being of the dimensions necessary for the work, is first laid down concentric with the spindle b', and levelled off the ground upon blocks. To the arm c', projecting from the spindle, the loam board d' is fixed by glands embracing two arms nailed upon it. This board is cut to form the bearing e' of brick and loam for the core, the bearing acting also by its sloping edge as a guard in closing the mould.

Its upper surface now forms the lower side of the cylinder flange. The board is then altered as shown at f' on the opposite side, so as to form the flange i, which is made simply of loam. This is the second stage of the work, and the flange must be dried like the bearing before it, to prepare for the next stage. It is necessary to form the flange singly, to be an additional bearing upon which the superstructure is founded. If it were cut at once out of the cope, the overhanging loam must give way.

The arm c' is now shifted up along the spindle sufficiently high for the next operation represented at Fig. 1, Plate XLVII. A loam board d is cut to the form of that part of the cylinder included between the extreme flanges, these, themselves, as we have stated, being made of loam and wood. The board includes the exterior outline of the circular exhaust passage; and it will be seen that, when set in motion, it touches the flange at the bottom, and a horizontal piece l projects from it to the top, to sweep a flat surface on the cope, upon which the square flange is to be laid. The arm c' is assisted in holding the board, by two pieces of iron at the bottom, screwed together upon the spindle and the board, the cope-ring h having been laid down upon the core-ring $a' a'$, surrounding the bearing e, with a little space between them. The steam-way pattern, Figs. 4 and 5, is set in its place in an inverted position, resting on the flange i. Its precise position will be ascertained by the loam board, which ought to touch it when it passes round. The

building is commenced upon the cope-ring; and having been raised upon the flange *i*, another ring *k* is bedded on the building, lying near into the loam board, with a segment cut out of it sufficient to clear the steam-way patterns on both sides. Upon this ring the building is continued till near the under side of the exhaust passage; at which place a similar ring *p'* is bedded on the structure, overhanging it sufficiently to sustain the building round the passage, at which place it is greater in diameter. Having built up the height of the passage indicated by the board, a layer of loam on the top is swept flush with the upper side of the projection, by means of a stick nailed on the board. This forms a parting surface, by which the cope is divided into two parts, the necessity of which is apparent on considering the method of placing the cores for the exhaust passage. After blackwashing the surface, a third ring *m*, with projecting snugs on its rim, is laid over it, being faced, however, with a layer of loam to protect it from the melted iron. The building is continued upon this plate till it reaches the top, when it is succeeded by another plate *n*, of a square external form, and somewhat larger than the square base plate of the casting immediately over it. The building is finally carried up to the horizontal piece *l*, which smooths off the upper surface with loam.

It will be remembered that the mould is, on one side, cut longitudinally throughout by the pattern of the steam-ways. On that side therefore it has to be completed; this object is attained by providing a cast-iron plate, done in open sand, fitting generally the interior of the pattern, and having three openings, through which the core-prints are passed when the plate is applied. It is daubed all over the inner face with stiff loam, and being set up in its place, the loam receives the impression of the face of the pattern. Lastly, the square flange pattern is laid over the whole, upon the bed prepared for it, preceded by the four stiffening flanges, and is surrounded with additional loam, flush with its upper side, to form a bearing for the top plate.

In the manner thus described, the external figure of the cylinder is formed. The whole mould from the bottom is lifted by the snugs on the cope-ring *h*, off the core-ring, upon which the two layers *e* and *i* are left. It is conveyed to a sufficiently large drying stove to be thoroughly dried.

Moulding the core is an operation comparatively easy, as it is a simple cylinder of brick and loam. In the first place, as the loam flange *i* has formed its impression on the interior mould under the plate *k*, it is of no further use, and is therefore broken away, leaving the bearing clean to receive the core, as represented on the right side of Fig. 1, Plate XLVII. *o* is the loam board in its proper position for working, having its inner edge set parallel to the spindle, and to the diameter of the cylinder required, and simply fixed to the arm at the top. A cylinder of brickwork *p* is first built up, being everywhere an inch or so clear of the board. A coat of loam is next laid on as usual, to fill up the clearance and complete the core. The board and the spindle being removed, the work is lifted away to the stove, on the core-ring *a′ a′*, by the snugs upon its rim.

The next business of the moulder is the formation of the smaller cores, which are to form the winding steam passages to the cylinder, of which there are three; the two supply passages *a a*, and the exhaust passage *b*. The two former being of the same shape, may be formed from one core-box, seen in plan and section, Figs. 2 and 3, Plate XLVII., for such kinds of cores are usually formed on three sides, and open on the fourth side to admit the material, which is shaped off on this side, by the edge of a piece of wood cut to the contour of the core, and drawn along upon the sides of the core-box as guides. The core for the exhaust passage is partly circular, and partly otherwise at the ends. Its formation is thus more complicated than that of the other cores. It is made in three parts; the centre part annular to embrace the cylinder, and formed by a loam board, and the terminations made in core-boxes, and fitted to the other. Fig. 4, Plate XLVII., is a vertical view of the method of making the annular core. It is built upon a portable square table convenient for small circular work generally, as it may be conveyed to the stove without the necessity of shifting the centre. The spindle turns by a conical pivot on its under end, moving in a socket, which is the only staying it requires. A block *a″ a″* is first prepared, being a plain built ring of which the exterior is smoothed with loam, and is made exactly to the interior diameter of the core and to the same depth. The core, seen in section at *b″*, is run upon the outside of the block to the necessary

thickness, in the course of which two wrought-iron angular rods are imbedded to the core to impart their thickness to it. At b' is shown the valve-face portion of the core, of which a' is the box, in section, for making it. The round core for the short, straight passage d, Fig. 5, is made of loam, being run up on a short iron centre.

In the making of these small cores, as in those of green sand, it is necessary that they be strengthened with iron rods bent to their form, so as to pass through the heart of them, and finished with eyes at their outer extremities, for locking to the face-plate. An open passage running through each core is formed, as in green-sand cores, by laying pieces of cord along the irons. These passages are of great importance, as upon them depends the escape, through the openings in the face-plate, of the otherwise confined air existing in the mould, while the metal is being run. The too close proximity of these passages, at any point, to the surface of the cores must be well guarded against. In such a case, the melted metal in contact with the core breaks into the interior of it, and intercepts the air in its escape, which aggravates the evil, by forcing it into the body of the metal, and thus rendering the casting unsolid. The accident even assumes, in some cases, a more serious aspect, by causing such an agitation in the metal as to render the cast utterly useless; indeed, we have even seen the metal already poured, almost wholly expelled from the mould, and sent in showers through the foundry, the occurrence being entirely attributable to an oversight of the nature referred to.

Fig. 6, Plate XLVII., is a side view in section of the mode of placing and fixing the cores for the steam-ways to the cylinder; $q\ q$ is the face-plate lined with stiff loam, which retains the impression of the steam-way pattern; $g\ g$ are the two cores, the nearer ends of which are passed through the openings made in the plate for them, and fixed there by small rods passed through the eyes of the stiffening irons. The ends are made with shoulders which bear upon the upper side of the plate, Fig. 6, which may be understood from the form of the prints in Fig. 5, Plate XLVI. The horizontal parts of the cores are supported at their proper distance off the loam work beneath them, by steeples stuck into it.

The mould and the cores having been well dried, they are

dressed and smoothed where necessary, and finished with a coat of coal-powder.

Fig. 5, Plate XLVII., is a vertical section of the whole mould, showing all the parts fitted to one another, so as to contain among themselves the vacant space, indicated by a white ground, into which the metal is delivered. The mode of depositing and putting together the mould is as follows: the main core *p p* is lowered upon its rings, from which it is never separated, into a pit dug in the floor of the foundry, sufficiently deep to receive the core below the surface. The exhaust-passage core, is next deposited in its exact position in its place on the top of the lower part of the cope, being sustained in the usual manner off the core by chaplets made of two pieces of strong hoop-iron, riveted on the ends of two studs, so as to have the necessary thickness of space. The lower part of the cope thus furnished, is next lowered over the main core into its place upon the core-ring, thus surrounding the core, and containing with it a space between, as indicated in the figure. Another set of chaplets are deposited upon the exhaust core, which, by being in contact with the upper half of the cope when placed above, prevent the core from floating off its seat when immersed in the flowing metal. This is a matter of greater moment than sustaining the core from below, as will be apparent on considering the great difference of specific gravities of dry loam and iron. In this case the upward effective pressure of the fluid metal upon the core, is proportional to the difference of their specific gravities, which being so much in favour of iron, the pressure upwards, sustained by the chaplets, cannot be much less than the weight of a body of iron of the same bulk as the core. Therefore, as a safe general rule, chaplets are, or ought to be, made of sufficient strength to resist the weight of a body of iron equal in bulk to the core, for the support of which they are destined.

The upper part of the cope having been let down into its place, the face-plate, with its cores fixed to it, Fig. 6, is let down in front of the vacancy in the side of the cope, till it arrives at the proper height, when it is set close into its place, and the end of the exhaust core receives *b′*, through the middle opening in the plate, and is secured on the outside by the eye. The branch core *d* is then set in and supported on chaplets, and over it a ring or

cake of loam *m l*, seen in section in the figure, is placed, being strengthened internally with iron, like the cores. The cake of loam forms by its inner surface the outer surface of the flange.

The mould being all finished below the top, the pit sand is rammed tightly round it, to enable it to withstand the pressure of the metal, air-vents being provided in a manner similar to those for the pan already described. The top plate *r r* is laid on lastly, holes being provided in it for the admission of the metal. It is covered in with sand, through which passages are led up to form the holes to the external surface as runners or gates.

CHAPTER XIV.

PLATE MOULDING; MOULDING MACHINES.

Where a very large number of small articles, such as door and coffin furniture, the ornamental nails used by upholsterers, small working parts of agricultural machines, sewing machines, and the like, are required, they are almost always plate moulded. Besides its employment in the production of an infinite variety of the small ware of the hardware trade, plate moulding has certain advantages which recommend themselves to the notice of the mechanician. As a matter of common occurrence, it is well-known that in removing the pattern from the sand, much damage is caused both to it and its impression in the sand by knocking and shaking it, in order to get it out. This damage is very much more serious in small pieces than in large ones. The mechanical engineer tries to obtain all his castings so correct, that there is little or no hand labour required for fitting them into the framework intended for them. This can only be done in some instances by resorting to plate moulding where the pattern is in such a position as to defy injury by shaking. This kind of moulding is most essential where every opening or projection has to be at a proportionate distance from the other.

In commencing the operation, a pattern or pattern plate of the articles to be cast from is prepared, either in iron, wood, or any other suitable material, in the following manner:—The pattern, prepared with an allowance for the thickness, is placed upon a suitable board, set upon a deep and solid bed of sand. A moulding box, about 6 inches larger than the pattern every way, is then placed upon the board; the pattern being set fair in the middle, it is rammed up and turned over another solid bed of sand; the board is then removed and the parting carefully made. The top part of the box is then put on to the part already rammed up, which is the drag; the gate pins are put in suitable places, and this also is rammed up.

The two parts are then separated, and a frame of wood, about

½ inch thick and 1½ inch broad, is placed on the parting, keeping the pattern fair in the middle. The outside of the frame is made up firmly with sand, so as to resist the pressure of the metal; a piece of iron, the same thickness as the frame, 2 inches broad and about 4 inches long, is placed on each corner of the under part of the box or drag, so that when the top part is placed on it, it will be raised up the thickness of the frame.

The frame and patterns are then removed, and the mould is carefully finished. The top part is afterwards placed upon the under part of the box, and the two parts are securely fastened together the metal is then poured into the mould, and the pattern plate is produced; this plate is formed with four cheeks on it, which are filed and faced to ensure accuracy in the moulding. The pattern plate being cast in the manner above described, it is cleaned up and fitted to the moulding boxes, the pins and snugs of which and checks in the plate being all fitted exactly to one another. The pattern plate may be used singly, that is, it may be turned over with the top part and drag of the moulding box, or two plates may be made, the face impression being taken off one plate, and the back impression off a different plate. When two plates are used, each plate must be accurately fitted and secured to a frame, which may be constructed of wood or iron, and furnished with guides, corresponding with the pins and snugs of the moulding boxes. The pins of the moulding boxes may be either simply faced, or steel fitting strips can be inserted into grooves formed in them by mandrils.

Another method of preparing what we may term the working plates, when the moulding plate is to be made by casting the patterns upon the face or faces of a plate, is to take a copper or other metallic plate, the surface of which has been tinned, and mould, in an ordinary sand mould, the half patterns of the articles to be cast. The tinned plate being placed in the mould box with the half mould upon it, fused tin, or an alloy of tin and lead, is run into the mould. There is thereby produced a moulding plate having on one face the half patterns of the articles to be cast, together with the necessary "gates," the cast patterns and gates adhering firmly to the tinned surface of the plate. Half patterns on opposite sides of the plate may be cast simultaneously in a similar way. Or instead of casting the half patterns simultaneously on

opposite sides of the plate, the half patterns cast on one side of the plate, may be used for moulding the half patterns to be cast on the opposite side of the plate. By this means, great accuracy in the positions of the half patterns on opposite sides of the plate, is obtained. This ingenious method was introduced by Messrs. Chamberlain and Smith.

The half patterns cast upon one or on opposite sides of the plate may be made of iron instead of tin. In this case, an uncoated iron plate is used, and on this iron plate the half patterns and gates are cast. After the casting process, the plate with the slightly attached castings upon it, is plunged for a short time in a bath of melted tin, the whole becomes coated with tin, and the other patterns are firmly attached to the plate.

When the patterns and plate are made in one piece by casting, the half patterns are moulded, and the half mould is placed in an open casting box. By pouring fused metal into the open box a plate of the required thickness, with the half patterns upon one face of it, is produced. When the half patterns are to be produced on opposite sides of the cast plate, two half moulds are taken and so adjusted that the distance between them is equal to the thickness of the plate to be cast. By the casting process a pattern or moulding plate is produced having the half patterns on opposite sides.

Fig. 1, Plate XLVIII., represents a plan of a metallic pattern or moulding plate made in either of the ways described; and Figs. 3 and 4 are edge views of the same taken at right angles to one another. The pattern plate is here represented as made with a number of half patterns on opposite sides, for moulding a series of gas fittings. The gates of the half patterns are marked *a*, and the core-prints of those articles which are to be cored *c c*. Holes are made at the corners of the plate.

In order to obtain great accuracy, the faces of the moulding boxes, which bear against the pattern plate, are planed very truly, and in addition to the ordinary pegs and snugs on the half moulding boxes, for holding them tightly together during the moulding and casting operations, in the corners of the half moulding boxes, holes are made, which take upon studs or projections on the corners of the other half moulding box. When the pattern plate is placed upon the lower half mould, the studs or projections take into the

holes in the corners of the pattern plate, and the position of the plate is thereby accurately and readily determined. When the pattern plate has thus been fitted upon the half moulding box, the upper half moulding box is placed upon it and fixed by the pegs and snugs, when the sand is rammed in and the pattern moulded from the upper side of the pattern plate in the ordinary manner.

Having moulded the required number of half moulds from the upper face of the pattern plate, the moulding boxes are inverted, and half moulds are now moulded from the opposite face of the plate.

For some articles, such as brass nails, plates with holes in them, for the pattern to go through, and also pulled out by means of leverage, are much in vogue.

The expense incurred in the first place in patterns for plate moulding is rather large, but so much can be done by the plates, of which many duplicates can be in use at the same time, that it has come into very general use, as year by year the machinists require better casts at decreased prices.

The mode of producing moulds by employing a plate having a passage through it exactly fitting the pattern, has long been practised in England. The plate is arranged on a table, and covered by a box; sand is rammed around the pattern, which at that time is caused to project up above the surface of the plate, and the pattern is subsequently withdrawn, through the hole or passage. In many cases the preparation of the plate, just described, is expensive, particularly when small cog-wheels are moulded in this manner, as the holes in the plate should fit accurately over the pattern. To remedy this, Messrs. Jobson and Ransome introduced a plan, by which the opening on the plate is formed somewhat larger than is required for the passage of the pattern, and without reference to its peculiar contour; and afterwards, when the pattern is in its place, a fusible metal, consisting of 8 parts of tin, 4 lead, and 1 bismuth, is poured or filled into the space between the pattern and the plate. For holding, or retaining the introduced metal securely within the opening through the plate, various plans, such as grooves cut into its thickness, will readily suggest themselves to the founder.

One of the advantageous points to be attained in the successful conduct of a foundry, is the facility of carrying on work in the

smallest possible space, and this is more particularly the case in towns where, as a rule, land is especially valuable. Moulding is an operation requiring considerable space, and with a view of limiting this as much as possible, moulding machines, for work involving much duplication, have been extensively employed. In addition, such machines effect neatness and cleanliness in carrying on the work, and in a measure obviate the necessity for employing very skilled labour; while the increase in the rate of production affords the most economical results.

Such a mode of moulding as that of Jobson's, described on p. 189, is a step in this direction; and another is the process introduced by John Downie in 1856 for moulding pipes and hollow cast ware, and applicable to a wide range of articles, generally of cylindrical or spherical form.

The internal pattern is made separately in core-boxes or otherwise in the ordinary manner; but the pattern for producing the external portions of the mould is fitted with a cam, in the form of a collar, resting upon adjustable bearings in the framework of the table on which the moulding flasks are rammed; a portion of the cam is concentric with the axis of the pattern, and the remainder eccentric so as to elevate the pattern between the two edges of the moulding table, and withdraw it again accurately by lowering.

The apparatus employed for this purpose is shown in Figs. 1 to 5, Plate XL., which represents it arranged for moulding a 28-inch socket pipe.

The moulding table R has two edges S S of its face, shown dotted, shaped so as exactly to fit the pattern T, when the latter is raised with its axis level with the edges S, as in Fig. 4. The pattern is fitted with a cam or collar U, at each end of which the portion from V to X, is concentric with the axis of the pattern, and the remainder eccentric. The cam U rests upon the adjustable bearing Y, and the axis of the pattern is guided by vertical slots in the ends of the moulding table. On causing the pattern to rotate, the eccentric portion of the cam, acting on the bearing Y, gradually raises the pattern till it bears on the point V of the cam, when the pattern is in its highest position, with its centre line level with the edges S of the moulding table, as in Fig. 4. The flask Z is then placed on the table and rammed up so as to form one half of the

mould, and the two faces S S of the table form the parting surface of the mould, being made fair for this purpose by planing, turning, or other means. The further rotation of the pattern upon the concentric portion of the cam from V to X, retains it in contact with the mould, and thus sleeks, smooths, or finishes the mould, until on reaching the point X, the pattern is gradually withdrawn as in Fig. 5; the flask Z may then be removed without danger of injury to the parting or junction surface, ready for closing and casting in the usual manner.

The same principle has also been adopted for making cores or internal moulds, by employing a core barrel made in three portions, two of which are hinged upon the third; the centre spindle is fitted with cams of the form above described, which act upon a V-piece inserted between the two free edges of the core barrel. By turning the centre spindle the V-piece is pushed out or drawn in, thereby expanding the core barrel or contracting it as required; by this means the use of straw or hay in core making is dispensed with.

By applying this method to moulding three-legged pots and other articles of this description, when several pieces of the mould are put together, "checks," such as are commonly required in the ordinary plans of moulding such articles, for protecting the partings of the moulds, are by the present plan entirely dispensed with, and the ugly scar left by them on the casting is avoided; and instead of the flasks being required in four pieces to form the mould, three are sufficient, the external mould being made in two halves with plugs inserted for the legs. Consequently several sizes of pots may be made with the same sized flasks; and while the plant is otherwise simplified and reduced in cost, increased efficiency is obtained, since by this arrangement little or no discretionary power is left in the hands of the workman.

A moulding machine of most ingenious construction was introduced some years since by R. Jobson. It is shown in Plate XLI. A A is the moulding table or bed, consisting of a rectangular cast-iron box, open at top and bottom, and furnished with a large cylindrical axis B B at each end, 6 inches diameter, turning in bearings on the side frames C C. The axes are prolonged at the ends, and counterbalance weights D D attached to them by arms, which can readily be adjusted by lengthening or shortening, so as to

balance the table with the mould upon it, leaving it free to turn upon the axes. The table turns half round, as shown by the two positions in Figs. 1 and 3, being prevented from turning farther by stops, E E, upon the ends of the moulding table, which catches in notches on the top of the frame C. On the top of the table A a plate F is fixed by screw-bolts, carrying the moulding box G, which is secured upon it by two inclined catches with handles H H, the plate F forming the ramming board upon which the pattern I is fixed, and the moulding sand rammed upon it in the ordinary way. The machine is shown as arranged for forming 8-inch mortar-shells, the pattern I being a hemisphere; any other pattern or form of flask within the limits of the size of the machine can, however, readily be employed, the only preparation requisite being to fix each pattern upon a bottom plate, having bolt-holes to correspond with those in the top of the moulding frame. This arrangement is so simple, that after the machine has been moulding shells, it can be changed and got to work again at moulding railway chairs, or other articles, within ten minutes' time.

As soon as the sand is rammed, the cover plate K is put on the box, by sliding it on the inclined snugs which hold it fast; the whole is then turned over with the moulding table into the reversed position, as in Fig. 1; this being effected by the simple pressure of pushing home the cover plate K, since the whole is balanced and turns freely upon the axes. In moulding shells, the pattern I is then withdrawn from the mould, sufficiently to make it clear the sand, by means of the screw and hand-wheel L. A rising platform, M, which slides in vertical grooves in the side frames C C, is then brought up by means of a lever O, to touch the cover plate of the box which is now at the underside, and the box is liberated from the moulding plate by releasing the two catches H H, simultaneously, by means of the second handles N N, fixed on the other ends of the spindles for this purpose. The whole is then in the position shown by the dotted lines in Fig. 3, and the platform M now descends, by means of the additional weight upon it, to the bottom position in Fig. 3, the platform being counterpoised by the balance weights P P. The mould is then removed, by sliding it off the platform on to a little railway placed at the same level, and the machine is made ready for repeating the operation, by screwing down the pattern

to its right place, and turning back the moulding table to its former position, ready to receive a second empty box.

The principle carried out in this machine, of turning over the whole moulding table with the mould and pattern upon it undisturbed, has the effect of saving all the labour of lifting the moulds; so that boys, who are sufficient for all the actual moulding work, are able to complete the process, instead of men being required to lift the heavy weights.

An advantage in average quality of work and saving of wasters is obtained, by avoiding all handling and risk of disturbing the moulds in lifting them off; they simply slide along a little smooth railway from the moulding machine to the casting ladle, which is fixed 7 feet 6 inches distant from the moulding machine, centre to centre. A very important point is also gained, by always replacing the pattern in its first position, while still inverted, thus preventing any particles of sand from interfering with the working parts of the pattern. It is an essential point in machinery applied to such purposes as the present, that it should be arranged so as to keep in good order for long-continued regular work, without requiring any care or nicety in management, that would interfere at all with the roughness of manipulation inseparable from such work, where expedition and economy of manufacture, combined with accuracy in the castings, are the objects to be accomplished; and the present machine has been found completely satisfactory in this respect. The result of the working of the moulding machine is so successful, that one mould, consisting of two railway chairs, is readily completed every minute on the machine; and the machine is found to keep so completely in working order, that the regular day's work of ten hours produces from 1000 to 1100 chairs, being at the average rate throughout of two chairs per minute. This rapidity of moulding by the machine necessitated special arrangements for casting, which we need not detail here.

To define the limits of any particular kind of moulding is somewhat difficult; but some conclusion may be arrived at, by a comparison between the plan above described with the moulding machine, and the old system.

In casting railway chairs by the old system, it was considered a good day's work to obtain 300 castings from one man and his boys,

and with the best plan the average does not exceed 480 per day. To produce this quantity, the man who rams up the bottom box has to lift the following weights :—

Bottom box	26 lbs.
Patterns	45 „
Sand	48 „
Ramming board	12 „
Total	131 lbs.

This total weight of 131 lbs. has to be divided by 2, as the box rests upon its edge while being turned over; therefore 131 lbs. divided by 2 = 65 lbs.

After turning it over the man has to

Lift off the ramming board	12 lbs.
Draw the patterns	45 „
Carry the box full of sand to casting stage ..	74 „
And 65 lbs. brought forward	65 „
Total	196 lbs.

which multiplied by 240, the number of boxes moulded to produce 480 chairs, 2 chairs in each box, gives 47,040 lbs., or more than 20 tons, to be lifted by a man during his day's work.

In Jobson's moulding machine, by using the turn-over table, a man has been known to make from 1000 to 1100 chairs per day, in producing which he had only to lift the empty box and cover plate :—

Bottom box	26 lbs.
Cover plate	9 „
Total	35 lbs.

which, multiplied by 550, the average number of boxes moulded, 2 chairs in each box, gives 19,250 lbs., or only 9 tons, to be lifted in making the larger quantity, against 20 tons in making the smaller quantity by the old plan, the latter requiring accordingly about 5½ times as much labour in lifting, per chair produced, as is necessary with the machine.

As we have seen, according to the ordinary mode the pattern halves are placed on a board, the mould box placed thereupon, and the moulding material put in; the box is then turned over, the

second halves of patterns put on, and the moulding material put therein; finally the patterns are taken out, and the runners made for the inlet of the melted metal. The defects of this method are that the patterns, by constant use, soon become defective, requiring constant repairs, and that the castings seldom are perfect. By the removal of the patterns the edges of the mould also become defective and have to be repaired. In moulding toothed wheels the repaired teeth become harder than the others, because the mould there is made wetter, and this causes unequal wear and tear, and consequent irregular working. To obviate this, plate moulding is resorted to, but the preparation of the moulding plate is undoubtedly expensive.

According to a novel mode of machine moulding one or more patterns are cast together with a flat plate from original patterns divided in halves; but with Woolnough and Dehne's plan, the patterns are cast together, with a plate having pivots at two opposite sides The original patterns not being divided into halves are first moulded in the usual way, and when both box halves are ready for the casting, a suitable pattern frame of the thickness of the plate mentioned, and having the pivots, is laid on one of the box halves, and the mould of the plate and half the pivot is made from it; the other half pivots are moulded in the other box half. The casting then is proceeded with, and the moulding plate so made, after that the pivots have been turned and the casting trimmed in the usual way, is suitable for the purpose of moulding from, and requires a moulding table or apparatus, which may be of the following description:—

In Fig. 1, Plate XLII., is shown Woolnough and Dehne's moulding table in vertical cross-section. Fig. 1, Plate XLIII., is an end elevation, partly in section, and Fig. 2, Plate XLII., is a plan, *h* is the moulding plate, which is also shown in Figs. 2 and 3, Plate XLIII., and Fig. 1, Plate XLIV.

The apparatus consists mainly of two hollow pillars A A′, screwed on to a cast-iron bed-plate *a*, and made to shift closer together or farther apart. In each of the columns A A′ there is a screw spindle *b b′*, which can be moved up and down by means of a worm-wheel *c c′* on a spindle *d*, which has a handle, or hand-wheel, *e*. The spindle passes through stuffing boxes *i* at the top of the columns.

To prevent the entrance of sand to the worm-wheels, they are covered by cases. The screw spindles *b b'* are also for the same purpose encased below in closed tubes. The screw spindles *b b'* have heads *g g'* above, which can turn thereon, and can be fixed by means of set screws *m m'*. These heads form the bearings for the pivots of the moulding plate, and also carry tubular casings *o o'*, which enclose the upper part of the screw spindles to prevent the sand-dust from entering. The moulding-plate pivots can be fixed in position by means of set screws *p p'*. To the inner side of the columns are fixed strong plates *r r'*, which form the rails for the wheels of a movable table *s*; these plates can, by means of their fastening screws fitting in slots, be adjusted in their positions. There must, of course, be a table apparatus for each width of moulding plate.

Figs. 3 and 4 are two views of the pattern for a sanitary pan; they show the mode of moulding with this invention, which is as follows:—The moulding plate *h* is first placed with its pivots in their bearings formed in the heads *g g'*, the one moulding box half is then placed thereon and fastened thereto by keys or by screws. The sand is now stamped into it, then the moulding plate *h* is raised, turned over on its pivots, together with the box attached, and lowered again. The plate is then loosed from the box and lifted off. The pattern lifts quite vertically out of the sand, as the plate, by means of the screw spindles *b b'*, can be adjusted exactly; when worn they are turned up a little, so that the worm-wheels come into exact gear. The finished box half, standing on the movable table *s*, is drawn away under the moulding plate and put by. By the turning over of the moulding plate *h*, it is made ready for receiving the second box half, as the side thereof is turned upwards. The second box half is then put on and fastened, and the process repeated.

The gates may be stamped into the second box half, but this is not absolutely necessary. This method of moulding can be exercised by any intelligent labourer.

CHAPTER XV.

MOULDING THE TEETH OF WHEELS.

The accuracy and perfection of the teeth of wheels are of great practical importance in all cases of gearing, and especially where large amounts of power are transmitted by them; and it is requisite that the transmission of power should be uniform and continuous through the teeth of the wheels, corresponding to the continued frictional contact of the two circles rolling upon each other. To maintain this uniform and continuous action in toothed wheels, all the teeth throughout the circumference of the wheel are required to be precise duplicates of one another in form, size, and spacing; and all to be placed in a perfect circle round the centre of the wheel. Should these conditions be imperfectly carried out, the essential continuous contact will be destroyed, and a serious intermittent knocking between the teeth will be caused, leading to the fracture of the wheel, and risking a stoppage of the machinery. Any defective fitting of toothed wheels also involves a waste of driving power, from the irregular shocks in transmitting the power; and, as a consequence, the wheel will not last so long in such a case, owing to the friction causing extra wear of the teeth.

In the earliest method of making toothed wheels, the teeth were chipped out by hand from the solid edge of the wheel, upon which they were set out and shaped to template. Subsequently the teeth were formed on a wood model of the wheel, and moulded from this model, according to the plan in general use.

What is called the pitch circle of a toothed wheel is simply the circle whose diameter is equal to that of a cylinder, the rolling action of which would be equivalent to that of a toothed wheel. It is the limit to which the wheel approaches, as the teeth are indefinitely diminished in size, and increased in number, the distance of the axes remaining the same.

The pitch of a wheel may, of course, be any quantity within certain working limits, but it has been found convenient to employ only a given number of standard values, instead of using an indefinite number for the pitch. Thus in cast-iron wheels of the larger class, the values most commonly chosen are, 1 in., $1\frac{1}{8}$ in., $1\frac{1}{4}$ in., $1\frac{1}{2}$ in., 2 in., $2\frac{1}{2}$ in., 3 in.; and it rarely happens that any intermediate values are necessary. Below inch pitch the values $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, and $\frac{3}{4}$ in., are generally sufficient; cast-iron wheels of lower than $\frac{1}{4}$-in. pitch are seldom employed, and for machinery of a less size, the wheels are commonly cut in a wheel-cutting machine. This system of definite values for the pitch has this advantage, that it limits the numbers of founders' patterns, though this again is not so much the case where wheel-moulding machines are employed. Any others, however, may be readily calculated.

The most convenient mechanical mode of calculating the pitch may be illustrated thus:—Draw the line A B, Fig. 1, Plate LI., and from the point A lay off the pitch seven times to B; then draw a line D E parallel to it, and say one-half longer. Upon D E mark off the length A B, and divide it into eleven equal parts, continuing the same scale of division farther at pleasure. Now, each of these divisions upon the line D E, counts four teeth to the radius of the pitch line. Thus, if 56 teeth be wanted, then 14 divisions on D E must be taken as the radius, because $14 \times 4 = 56$. If an odd number of teeth be wanted, then the first division on D E must be subdivided into four equal parts, each of which will count one tooth in the radius required. Thus, if 59 teeth be wanted, then the radius of the wheel will be $14\frac{3}{4}$ divisions upon D E, because $14\frac{3}{4} \times 4 = 56 + 3 = 59$. Example. Required the diameter of a wheel, the pitch being 2 inches, and the number of teeth 48.

Here the line $AB = 14$ inches; and 11 divisions upon D E also $= 14$ inches; therefore, one of these divisions is equivalent to the eleventh part of 14 inches, that is, $1\frac{3}{11}$ inch. Now, each of these divisions, considered as units of the radius, counts four teeth, and as the wheel is to have 48 teeth, the radius will have $\frac{48}{4} = 12$ such units; that is 12 times $1\frac{3}{11}$ inch $= 15\frac{3}{11}$ inches. The diameter sought is therefore $30\frac{6}{11}$ inches.

The same may be done more simply and more directly by this

arithmetical rule:—Multiply the number of teeth by the pitch, and the product by $\cdot 16$ for the radius, or by $\cdot 32$ for the diameter.

Thus	Or
$48 =$ No. of teeth.	$48 =$ No. of teeth.
$2 =$ the pitch.	$2 =$ the pitch.
96	96
$\cdot 16$	$\cdot 32$
$15\cdot 36 =$ the radius.	$37\cdot 72 =$ the diameter.

This rule is identical in principle with that for finding the diameter of a wheel when the pitch and number of teeth are given. Instead, however, of dividing by $3\cdot 1416$, we multiply by its reciprocal, thus $\frac{1}{3\cdot 1416} = \cdot 3183$ or $\cdot 32$ nearly for the diameter, and by $\frac{32}{2} = \cdot 16$ for the radius. We have therefore these rules:

$$\left.\begin{array}{l} \text{No. of teeth} \times \text{Pitch} \times \cdot 16 = \text{Radius;} \\ \text{or} \quad \text{No. of teeth} \times \text{Pitch} \times \cdot 32 = \text{Diameter.} \end{array}\right\} \quad \text{(A)}$$

From this rule for finding the radius or diameter of a wheel when the number of teeth and pitch are given, we can easily deduce the rule for finding the pitch when the radius or diameter and number of teeth are known. Thus, it is clear that if the Rule A be true then must the following be true also—namely:

$$\left.\begin{array}{l} \dfrac{\text{Radius}}{\text{No. of teeth} \times \cdot 16} = \text{Pitch.} \\ \text{and} \quad \dfrac{\text{Diameter}}{\text{No. of teeth} \times \cdot 32} = \text{Pitch.} \end{array}\right\} \quad \text{(B)}$$

For example, the radius being $= 15\cdot 36$ inches, and the number of teeth $= 48$, then to find the pitch we have

$$\frac{15\cdot 36 \text{ in.}}{48 \times \cdot 16} = \frac{15\cdot 36 \text{ in.}}{7\cdot 68} = 2 \text{ inches pitch.}$$

The rule expressed in words is this:—Multiply the number of teeth by $\cdot 16$ and divide the radius by the product, and the quotient is the corresponding pitch.

Similarly to find the number of teeth the radius and pitch being given, we have

$$\left.\begin{array}{l} \dfrac{\text{Radius}}{\text{Pitch} \times \cdot 16} = \text{No. of teeth.} \\ \text{and} \quad \dfrac{\text{Diameter}}{\text{Pitch} \times \ 32} = \text{No. of teeth.} \end{array}\right\} \quad \text{(C)}$$

That is, multiply the given pitch, in inches or parts, by ·16, and divide the radius by the product, the quotient is the number of teeth.

As an example of the application of this rule, let the radius as before be 15·36 inches, and the pitch 2 inches, then we have

$$\frac{15 \cdot 36 \text{ in.}}{2 \text{ in.} \times \cdot 16} = \frac{15 \cdot 36 \text{ in.}}{\cdot 32 \text{ in.}} = 48, \text{ the number of teeth.}$$

It is hardly necessary to observe that these rules are not perfectly accurate, it is impossible indeed to make them so; but they are sufficiently near approximations for practical purposes. When very great accuracy is required, more elaborate methods may be employed, from which it would be found that the radius of a wheel of 48 teeth and 2-inch pitch, instead of being 15·36, as found by the rule above, is more nearly 15·29 inches, and more nearly still 15·2898 inches, but even this is only an approximation, and could be carried closer without much advantage in works of any considerable size.

To determine the proportions of a wheel we have the following empirical rule:—

Divide the pitch into 15 equal parts, take 7 of these parts for the thickness of the teeth, and 12 of them for its length, namely $5\frac{1}{2}$ from the pitch line to the point, and $6\frac{1}{2}$ from the pitch line to the root. Make the rim equal to the thickness of the tooth, arms equal to the same, and boss equal in thickness to the pitch.

Or by calculation we have

$$\left.\begin{array}{l}\text{Pitch} \times \cdot 48 = \text{thickness} \\ \text{Pitch} \times \cdot 8 \;\; = \text{length}\end{array}\right\} \text{of tooth.}$$

The following is the mode of dividing the pitch into 15 equal parts as required by the rule:—

In the diagram, Fig. 2, Plate LI., draw the line A C, and mark off upon it 15 equal parts as required; draw A I perpendicular to A C, and equal to the given pitch, then draw I C, and in the triangle formed draw the 15 parallels to A I, and the pitch will be divided as required.

From the diagram, to get the thickness of the tooth, set one point of the compasses at 7 in the line I C, and the other at 8 on the line A C; the line joining these points is the measure of the

thickness of the tooth. Similarly the line H, joining the points 12 in the line I C, and 3 in the line A C, is the measure of the length of the tooth, and this is equivalent to 5½, equal to the line F, and 6½ equal to the line G.

Another way of getting the diameter from the pitch is shown in Fig. 3.

Draw the line A B = 22; then draw B C = 7, and perpendicular to A B. Next draw A C, and the scale is complete.

For a wheel of 10 teeth lay off the pitch ten times to D, and draw D E parallel to B C, and it will be the diameter of the pitch circle D *b* E *a*. It will also be the radius of a wheel of 20 teeth, and half the radius of one of 40 teeth, and so on, of the given pitch.

Fig. 4 is a scale of a still more convenient kind, and ought to be constructed on a large size for general use in a workshop, as it not only saves time, but the wheels made by it are all of the same proportion of parts. The diameter of any wheel is found from it simultaneously with the thickness of tooth, width of space, &c. As here laid down the scale is adapted to wheels of any pitch, from ½ inch to 2 inches inclusive, one-eighth the size.

The method of making the scale is the following:—Draw the line A D, and from C draw C B perpendicular to A D. Transfer the divisions 1, 2, 3, 4, &c., from D E of a diagram similar to Fig. 1 to C D of Fig. 4, and number the parts thus transferred 4, 8, 12, 16, 20, &c., as each division of the primary scale is equal to four teeth. To do this, all the figures should be drawn *to the same scale;* it will be seen that unfortunately this is not the case on Plate LI., as Figs. 1, 2, and 3 are on a larger scale than Fig. 4. Next, transfer the line A I of Fig. 2 to C A of Fig. 4, and this is equal to the pitch. Divide the line C B into 16 equal parts to B, and join B A, B D. Through the points of division on the line C B draw lines parallel to A D, terminating in A B and D B. Then each parallel from the line C B to its point of termination in D B is the radius of a wheel with 60 teeth of the particular pitch marked against it on the line A B. Similarly the parallels express the radius of any wheel having less than 60 teeth, when measured only to the corresponding point in the line joining B, and the divisional point on C D, against which the number of teeth is found.

Thus the radius of a wheel of 48 teeth and $1\frac{3}{4}$-inch pitch is $a\,b =$ 16·36 inches.

For the proportions of the teeth, rim, &c., set off C G = to the length of the tooth $= \frac{12}{15}$ of the pitch, that is, = the line H in Fig. 2, also the thickness of the tooth, arm, and rim C F $= \frac{7}{15}$ of the pitch; the length of the tooth from the pitch line to the root = E G $\frac{6\frac{1}{2}}{15}$ of the pitch, that is the line G in Fig. 2.

This scale may be used when the number of teeth exceeds 60; thus, for a wheel of 92 teeth and 2-inch pitch the radius is found by setting off in the compasses the whole line C D, and also that part of it from C to the point marked 32. For odd teeth make use of the first four divisions, as explained under Fig 1.

To set off a spur-wheel with 32 teeth and 2-inch pitch draw a line A B, Fig. 5, Plate LI.; take A as a centre, and lay off A B = the distance from C to 32 on C D of Fig. 4; that is = the radius of the pitch circle. Through the points A and B, and perpendicular to the line A B, draw the lines A K and B J. From A, the centre, set off the radius of the shaft = A C, and from C lay off the pitch = C D for the thickness of the boss; then with the distance C B of Fig. 4 in the compasses, set off B E for the length of the tooth from the pitch line to the point; and in like manner with the distance E G of Fig. 4 in the compasses, set off B F for the tooth from the pitch line to the root. Again, from F set off F G = to C F of Fig. 4 for the thickness of the rim; and upon B J set off the width of the tooth, and upon A K the length of the boss, draw K L and D L to define the boss. Also draw M M parallel and = to G E and join M and L. H I is the face-bar.

Next divide the width of the rim into as many parts as there are thicknesses of timber in it, 1, 2, 3, 4, 5, the face-bar being broader and thicker than the others. The diagram, Fig. 6, is the form of the templet for cutting out the deal, 2, 3, 4, 5, into 8 lengths each; this templet should be of course quite dry and free from shakes. The arms are next to be cut out of the requisite width, with their two opposite sides quite parallel, so that they can be properly fastened to the face-plate in turning the outside rim.

In gluing up the rim, fix a wooden face-plate, of sufficient size to take in the diameter of the rim which is to be marked upon it,

on the iron one of the lathe, and turn it up perfectly true. The size, however, must be kept slightly greater than the diameter of the rim to allow for subsequent dressing. This done, clean one side of the segments marked 1 in Fig. 5, and fit them to the face-plate; joint their ends and sprig them on temporarily to the face-plate. When they are thus all fitted on, take them off one at a time, and glue paper between them and the face-plate; fasten them with sprigs, which are to be left in such a way as to be easily pulled out with the pincers when the glue is set. The segments 1 are next turned on the face, segments 2 fitted on in the same manner; afterwards in succession the segments 3, 4, and 5, always observing as the sprigs are pulled out to fill the holes with wooden pins and glue.

For turning up the outside of the rim and teeth, and pitching the teeth, an iron face-plate must be used, of a suitable diameter, and provided with slots and holes in it for screws, so that 4, 6, or 8 arms can be screwed on; likewise a recess in the centre about 3 inches diameter, and ½ inch deep, with a plate of iron to fit it, for adjusting the arms to the centre. When these are scarfed and blocked at the centre to strengthen them, as shown in Fig. 1, Plate LII., where A A are the arms and *a* the strengthening blocks, screw the small iron plate upon the centre of the arms, and having fitted this into the recess in the centre of the face-plate, the arms also are next to be firmly bolted to the face-plate. Reduce the arms to the exact length, and fit the rim upon them; screw the face-bar of the rim to the arms, and glue or sprig two small blocks temporarily, one on each side of an arm, on the other edge of the rim, so that the arms can be taken off when it is turned. It is not necessary to fit in the face-bars of the arms, until the teeth are all finished, at least in spur-wheel patterns.

It must be understood that the three pieces in Fig. 1, Plate LI., forming the six arms, are sunk flush into one another, from which it follows that the depth of each piece being divided into three parts, two of these parts must be scarfed out for the reception of the other two pieces. Thus, Fig. 5 is a side view, and Fig. 5*a* an edge view of the two outside pieces, *a*, *b*, *c*, *d*, of Fig. 1, and similarly Figs. 6, 7, 8 are one side and two edge views of the middle piece *f g*. The manner in which the scarfings close with

one another is observable in the external view of the centre, Fig. 1. We see, then, that a third of the width is left in scarfing, and this is necessarily the case when the pattern has six arms; were it formed with four arms, one-half the breadth would be left, and only one-fourth were the pattern made with eight arms.

When the outside of the rim is turned up according to the drawing, the next business is to divide or pitch the rim into as many divisions as there are teeth required. These divisions are to be carefully marked off by lines drawn upon the rim across its breadth. There are two modes of attaching the teeth, either they may be fixed by screws with glue, or they may be dovetailed into the rim. This last is preferable for large wheel patterns, and in shops provided with a machine for wheel cutting, it is found to be by far the most expeditious mode; when the pattern is small and of small pitch, the teeth may be simply sprigged on with glue.

The teeth ought to be of hard wood, such as plane tree or beech. Baywood and cedar are also used, but plane tree is preferable, at least for small wheels.

The teeth being blocked and fixed lengthways across the rim with glue, pieces of ½-inch deal are then glued betwixt the teeth; these pieces are marked *s s* in Fig. 2, and their use is to prevent the ends of the teeth being split in turning; when the glue is dry, the teeth are to be turned to the length and width required. The pattern is then ready to have the pitch circle C C drawn upon it.

The circle being accurately and finely drawn, the next business is to divide or pitch it into 32 equal parts of 2 inches, that is, from A to C on scale Fig. 4, Plate LI. The radius in this case will be very nearly 10⅛ inches, that is, from C to 32 on the scale line C D. The curves of the teeth are next to be described. The pitch in this instance is the radius from the pitch line, both to the point and root of the tooth; therefore place one leg of the compasses on O, Fig. 2, the other opened 2 inches will describe the curve *r p*, and placed on *a* will describe the curve *r q*. From *r* to *e* set off the thickness of the tooth = to G E in Fig. 4, Plate LI., and describe the curve *e t* from *v* as a centre. Draw in the other curves in the same manner, and when they are set out on one

side, square the lines across to the other side at four points, taken consecutively at right angles to each other, taking care that on both sides the lines accurately correspond in position, otherwise the teeth will twist, and will neither leave the sand clearly in moulding, nor work well when cast. The teeth are also frequently struck out, as in Fig. 7, Plate LI., the pitch point A being the centre from which the point of the next *e t* is struck with a radius A E, the portion *e g* being radial.

Many other methods can be named for striking out the teeth, but for these, including the epicycloidal mode, the reader had better refer to separate treatises. The best of these is Thomas Box's 'Practical Treatise on Mill-Gearing,' which includes the most advanced and scientific practice in respect to every problem which the founder may have to solve, if largely engaged in casting toothed wheels.

Fig. 2 shows part of a wheel after being turned and set out with the teeth drawn upon it preparatory to their being cut.

Fig. 3 shows in section the mode of constructing a wheel with the feather bars in the middle, the feathers of the arms and rim being glued on when the wheel is being built upon the face-plate. Fig. 9 shows half of the wheel finished. A A is the pitch circle, *r* the root, *p* the point, *r p* length of tooth; D D the rim of wheel, H the face-bars, F the arms, G the boss.

To set out a pair of bevel wheels, one with 44 and the other with 32 teeth, in accordance with the diagram Fig. 4, Plate LI.

Draw the lines A and B, Fig. 1, Plate LIII., so as to form a right angle with each other at F; on the line A, set off the radius or half the diameter of the large wheel from F to C, and the radius of the other from F to D; and from the points C and D draw the lines C E and D E perpendicular to the lines A and B, and forming a right angle at their point of intersection E; draw the diagonal F E, and through the point E draw G H so as to intersect it at right angles. Next lay off the length of the tooth from the pitch line to the point from E to *a a*, and also the length from the pitch line to the root, from E to *b b*, the thickness of the rim from *b* to *c*, and the width from E to I, then draw the line I parallel to G H, and produce the lines *a a, b b, c c*, from the points marked upon G H to I, so that were they continued, they would

meet F as a centre. From *a* to *b* is the clearance of tooth from point to rim when the wheels are working to the pitch line.

Draw the lines K and L, and from them set off the thickness of the face-bar, arm, &c., as already described under Fig. 5, Plate LI., and finally describe the curve M M, so as to touch the back of the rims.

The dotted curve shows the angle at which the wheels are to work, the larger one at an angle of 35 degrees, and the smaller at an angle of 55 degrees. Their ratio is 8 to 11, and is thus found: set down the number of teeth in the wheels, and find their least common multiple; that is, the least number that can be divided by both numbers without a remainder; in this case the least common multiple is 352, then $\frac{352}{44} = 8$, and $\frac{352}{32} = 11$, and the quotient 8 and 11 express the ratio.

Or the ratio may be found more conveniently by finding the greatest common measure of the numbers, that is, the greatest number that will divide them without a remainder, and dividing the number of teeth in each wheel by it; thus, 4 is the greatest common measure of 44 and 32, and the quotients of these numbers by 4 are 11 and 8.

It is hardly necessary to observe that it often happens that a pair of wheels have no other numbers to express their ratio than their respective numbers of teeth; thus, the ratio of a pair having respectively 27 and 53 teeth is expressed by those numbers, seeing that they have no other common measure than 1.

Any other pair of bevel wheels may be set out in the way described. Thus, supposing a wheel of only 28 teeth was required to work into one of 44, from the point E to N, Fig. 1, Plate LIV., set off the radius of the smaller wheel and draw the line N at right angles to the line N E till it meets the line F E upward as before.

Fig. 2, Plate LIII., shows the manner of gluing up the rim. The segments, No. 1, are glued to the face-plate with paper betwixt, and Nos. 2, 3, 4 are glued on so as to project over, as shown in the figure, and so that the bevel can be obtained. The inside is turned up to *c c* on Fig. 1, likewise the inside and outside edges. The rim is then taken off the face-plate. The arms are to be fastened to the iron face-plate, in the same manner as in making spur-

wheel patterns, with face-bars upon them. Some, however, put on back-bars instead of face-bars, and then the arms only are screwed upon the face-plate. The arms being reduced to the proper length, the rim is then fitted upon them and turned on the outside, like the quarter A in Fig. 3, ready for the teeth being glued on. The dotted circle is next to be drawn to divide or pitch the rim by; from the point A the equal distances *b b* are marked off, and from these points small arcs intersecting in *c* are described; the points A and C being joined, we have the line *a c* as the square line or axis ot the tooth. From *a c* lay off half the thickness of tooth on each side to *d d*, from *d* divide or pitch the rim upon the dotted circle into as many parts as there are teeth required; set a bevel to the line *d*, and draw lines across the rim at all the divisions to fix the teeth by; these being glued and sprigged on, set pieces of deal between them, to prevent their splitting when being dressed in the lathe. The quarter of the wheel marked B is turned up with the teeth set out; *e e* are the pieces betwixt the teeth, *f f* superfluous wood to be cut away, *c* is one of half of the wheel finished.

In setting out a bevel wheel, the teeth are drawn over to the inside in four parts, as in a spur-wheel pattern. To obtain the pitch of the inside, two or three teeth should be drawn over, and as a precaution, at least one quarter should be tried in case of inaccuracy.

It will be seen that wheel moulding from patterns thus made, involves the necessity of having a separate expensive pattern, for each wheel that differs in form and pitch of teeth, as well as in diameter. The result has been a vast collection of toothed-wheel patterns, to meet the requirements of ordinary trade demands; and this stock has become so costly, in the expense of construction and of the storage space occupied, that it has led to an objectionable limitation in the range of pitch of wheels, in order to reduce the extent of the stock of patterns. The use of wood patterns for entire wheels involves further, the practical objection of liability to distortion, both in the general contour of the wheel, and in each tooth, owing to the irregular effects of expansion and contraction in the component parts of the pattern, as well as the unavoidable risk of variation in the forms and dimensions of the several teeth, in

consequence of the different finish that each receives. The uncertainty, too, attending the drawing of an unwieldy pattern from its mould, and the distortion of the pattern that occurs from its lying in damp sand for a considerable time, are additional obstacles to the manufacture of a toothed wheel from the ordinary wood models with the correctness that is desirable.

The only method of overcoming these difficulties is by employing a small segment as the pattern, and moulding the entire toothed circumference by repetition of this small portion; employing mechanical means for lowering and raising it, and for spacing out the teeth round the circumference of the wheel, so as to obtain the same certainty of accuracy throughout, as is shown by a wheel divided and cut in a machine. This process was introduced by Mr. P. R. Jackson, and carried out with greatest accuracy; and until the advent of his most valuable machine it may be said that no really correct toothed wheels were cast.

The object of G. L. Scott's wheel-moulding machine has been to extend the application of this process by the use of a portable machine, of small size and cost, that can be easily applied for moulding a toothed wheel in any part of a foundry. Having moulded one wheel, the machine can be fixed at another place for use, or be put away until required again, in the meantime leaving the foundry floor clear and in the usual condition for ordinary work. It will enable any foundry to supply with rapidity and economy of manufacture wheels possessing the absolute accuracy which results from the use of a machine. Plates LIV. and LV. illustrate Scott's machine.

The pedestal A supports a centre pin B, which has a collar to bear upon the pedestal, and is provided with a projection that fits into a recess in the top of the pedestal, whereby it is prevented from turning in its socket. The spindle C is bored to fit on the centre pin B, and is turned to pass up through the rest of the apparatus, which it supports, as shown in section in Fig. 4, Plate LIV. Set screws placed in the spindle C are used to fix it firmly on the centre pin B, and this being secured in the pedestal a continuous vertical spindle is thus obtained. Loose collars provided with set screws and bored to fit the centre pin B are used for the purpose of elevating the apparatus above the pedestal A, in order the

more readily to adapt it for moulding different breadths of wheels. One of these collars is shown in Fig. 4, Plate LIII., and they are of 1, 2, and 3 inches in thickness respectively.

On the spindle C is carried the head D, shown in section in Fig. 4, Plate LIV., and Fig. 5, Plate LV., and in this head slide the radial arms E E, connected together at their front ends by the transverse piece F, which forms the bed for the vertical sliding ram G. The arms E E are secured to the head D, in any required position, by four square-headed bolts passing through slots in the arms, and through ears cast on the head; these bolts being screwed up, bind the arms and head firmly together. The spindle C being firmly secured in the pedestal, forms a stationary centre pillar for the machine, on which the head D is free to turn; and on the top of the spindle is keyed the worm-wheel H, from which a connection is made to the arms E, by the dividing apparatus shown in Figs. 1 and 3, Plate LIV. and Plate LV. This consists of a worm I gearing into the wheel H, and the change wheels J J J, the uppermost wheel being on the worm-shaft, and the lowest one keyed on the shaft K, which is carried by brackets on the arm E, and is provided with a loose collar acting as a bearing, so that the shaft may be withdrawn for altering the change wheels. The swing frame L carrying the change wheels, is sufficient for two intermediate change wheels if required. On the shaft K is fastened a spring handle M, which fits a slot in a disc that is divided, to guide the workman in the number of turns to be given to the shaft. The traversing screw O is carried by brackets on the arm E, and passes through the nut N bolted to the head D, so that by turning the screw O by the hand-wheel at the end, the arms are moved in or out, to suit the varying diameters of wheels to be moulded.

On the slide bed F fits the vertical sliding ram G, which is held in by the cover R, shown in section in Fig. 2, Plate LV., and a hand-screw S retains the ram in any required position. The bottom of the ram is bored to receive the angle bracket T, which is secured in it by steady pins; and to this is attached the segment pattern U of the wheel teeth to be moulded. The ram is moved up or down by a hand-wheel Y, having a worm gearing into a worm-wheel, on the shaft of which is a pulley Z; from this pulley two chains pass in opposite directions, the one being secured

to the bottom of the ram and the other to the top, and kept always tight by means of two locknuts. An adjustable brass collar W is fitted on the ram, for indicating to the moulder when the ram is sufficiently lowered. An eye-bolt is fixed on the top of the centre pillar C of the machine, for attaching the foundry crane in order to remove the machine.

The process of moulding a wheel with this machine is as follows:—A core-box for the arms of the wheel is first prepared, and also two radial boards for strickling or sweeping up the form of the top and bottom of the wheel in the sand, which are shaped to the profiles of the face and back of the wheel. The top board P in Fig. 4, Plate LIII., has on its lower edge the profile of the back of the wheel; and the bottom board Q has also on its upper edge the counterpart profile of the back of the wheel, and on its lower edge the profile of the face. A pattern is also made of a segment of the toothed rim of the wheel, consisting of two teeth only, which permits of moulding one space at a time.

A secure and steady foundation for the moulding machine, is obtained by sinking in the sand of the foundry floor, in the desired situation, the pedestal of the machine, which is bolted to a cast-iron base plate about 4 feet square; sand is then rammed solidly upon it, and the pedestal levelled so as to be truly vertical. Another form of pedestal is shown in Fig. 2, Plate LIV., which is used for fixing in the sand without a base plate. The top of the pedestal is placed about 15 inches below the floor level, this distance determining the greatest breadth of wheel that can be moulded. The centre pin B of the machine is then placed in the socket of the pedestal, for the purpose of forming the mould for the bed of the wheel, and also to mould the top box or other arrangement used to cover the mould for casting: the rest of the machine being laid aside for the present.

In Fig. 4, Plate LIII., is shown the loose collar V which is placed upon the centre pin B, of such thickness that its upper face is the same depth below the floor level, as the breadth of the rim of the wheel to be moulded; so that the back of the wheel is level with the floor, for convenience of fitting the top box on. This lower collar V is fixed by a set screw, and an upper loose collar X is also fitted on the centre pin B by a set screw, with its upper face

at the same height above the collar V as the breadth of the rim of the wheel; the lower collar thus exactly indicates the level of the bed and face of the wheel, and the upper collar that of the back of the wheel. The hole is well filled up with sand to the level of the upper collar; and the iron trammel carrying the top board P is placed upon the spindle B, and worked round the collar X, forming a mould of the back of the wheel, which is lightly sprinkled with parting sand to torm the parting for the top box. An ordinary top box, or other sufficient covering, is then placed on, and rammed up with sand; and the top box is staked in the ordinary manner, for the purpose of marking its correct position relatively to the bottom part of the wheel, by stakes driven into the sand, and fitting by the side of corresponding ears upon the top box. The top box is lifted clear off, carrying with it the impression of the back of the wheel; which impression is finished by turning the box over, and strickling it again with a second trammel that carries the bottom board Q. A centre is provided in the top box for this trammel, by means of a loose collar, in which are two bolts that pass through the top box and are fastened across the bars of the box. This loose collar fits the spindle B, and is drawn from it with the top box, thus fixing a strictly accurate centre. By this arrangement the centring collar can be readily fixed upon any ordinary top box, giving strict accuracy in the moulding, without requiring any special boxes for the purpose.

For forming the bed of the mould the top collar X is then removed, and the mould being dug out to the level of the bottom collar V, the sand is swept with the bottom radial board Q, worked round upon the bottom collar V. This forms the mould for the lower and outer faces of the teeth, and finishes the mould ready to receive the teeth and the cores for the arms; and as both the back and the face of the wheel have been struck from the same trammel and the same centre, perfect accuracy is ensured in the wheel.

The segmental pattern of the teeth U, Figs. 3 and 4, Plate LV., is then fitted truly square and central, and secured by screws upon the angle bracket T of the vertical sliding ram G, Fig. 3, Plate LIV. The upper portion of the machine is then placed upon the spindle B, the trammel having been removed, and

the fixing screws in the spindle are screwed up, to maintain the central axis continuous through the machine. The segmental pattern U is adjusted by the traversing screw O to the correct radius of the wheel, measuring from the top of the tooth to the centre of the machine. The ram G is then lowered to the level of the bed of the wheel, and secured at that point by the locking screw S; and the brass collar W is adjusted on the ram and fixed by a set screw, to ensure the ram always stopping at the same level, when lowered for moulding each successive tooth. The locking screw S prevents the ram rising from the pressure of ramming the sand. One space of the wheel teeth is then moulded, by ramming the sand in the space left between the pattern and the edge of the mould previously formed by the strickle board. The locking screw S being released, the ram carrying the pattern is raised clear of the mould, and should be traversed round through the exact distance of the pitch of the wheel, by means of the dividing handle and the change wheels, previously arranged for the required pitch. The segmental pattern is again lowered, and a second space moulded as before.

When all the teeth have been moulded, the fixing screws of the centre spindle are released, and the whole machine is lifted away, by the foundry crane laying hold of the eye-bolt on the top of the spindle, leaving the mould entirely clear to receive the cores for the arms and boss. The hole in the top of the pedestal is fitted with a cover to keep out the sand, and is then covered over with sand, which protects the pedestal against the action of the hot metal. The centre core for the wheel is adjusted as usual from the circumference, and the cores for the arms are set to their places, by means of wood gauges showing the thickness of the arms and rim. The top box is then put on, to cover the mould, being placed in its correct position by stacks previously mentioned; the gate or runner is formed, the box duly weighted, and the whole is ready for casting.

Another good machine for wheel moulding is that invented by Wm. Whittaker, Oldham, which is shown in plan and section in Plate LVI.

A is a circular framework cast in one piece, and supporting the other parts of the machine. B is a circular table, and to this

is keyed a very accurately finished dividing wheel M, containing 240 teeth, or some other equally divisible number, by which the table is revolved, and each revolution is divided into the number of teeth required in the wheel to be moulded, motion being communicated through the change wheels O P, from the handle N, to the worm C, working in the worm-wheel M.

The dividing wheel M and the worm C are well protected from the dust and grit, which accumulate in a foundry, and if lodging on the worm or wheel, would be very injurious to such an important part of the machine. D is a turned pillar fitted in the socket R, in which it slides up and down to suit the depth of wheel to be made, and supported by the rack E. The pillar will revolve to obtain any radius required, from the centre J to the pitch line of the pattern T.

F is a horizontal slide, used chiefly in making worm-wheels. At the end of the slide F is the vertical slide G, for lowering and raising the pattern T to and from the mould.

Having ascertained the sizes of wheels to be made, it is necessary to set them out full size in section on a drawing board, in order to get the proper form of strickling board and core-box for the arms. It is also necessary to draw in full a short segment of rim, showing the proper form and size of a few cogs. The block or segment pattern is made with two teeth only, as with Scott's machine.

The moulding from two teeth is executed with greater precision than would be the case, if the moulding was to be done from a pattern with a greater number of teeth; because one and the same tooth is moulded throughout the whole wheel; so that with a good division wheel, all the teeth in the mould are identical.

The next part of the pattern is the strickling board, shown in Figs. 3 and 4, Plate LVI., the former for bevel and the latter for spur-wheels. These boards are shaped to the exact section of the wheels intended to be made, the edge *a b c* forming the lower part of the mould, or that part which is to receive the teeth; and the edge *d e* forms the moulds for the back part of the bevel, or top side, of spur-wheels, or in other words *a b c* form that part of mould made in the bottom moulding box, and *d e* form that part of the mould made in top box; the edges *c* and *e* forming the parting

surface for the two moulds. The board is bolted or screwed to the iron bracket V, through which is bored the hole x, to fit on the spindle J, in the centre of the machine. The same bracket is used for all wheels, as the boards can be detached by taking out the bolts or screws.

The other part of the pattern is the core-box for space between arms, rim, and boss. It is not necessary to enter into any description further than that it is used to form the section, rim, boss, and space required between the arms of wheel intended to be made, one box serving for the whole wheel.

The moulding boxes to be used with this machine are bored, turned at the joints, and fitted together in pairs, the bottom box L only being used on the table of the machine. The slides F G, to which are attached the whole of the top part of the machine, are bolted to the top of the pillar D through the flange D^1. By revolving the pillar D, the whole of the slides F G and appendages are moved from over the table B, leaving the table quite clear and free from all obstructions. The moulding box L is then placed on the table B. The centres of the table and moulding box are bored one size to fit the centre spindle J, which is dropped into both centres, after placing the box on the table. The box is then filled with sand, and rammed in the usual way, leaving sufficient space for filling or facing up the mould with new sand.

The strickling board, Fig. 3 or 4, is then applied; the hole x in the bracket V, to which the strickling board is attached, being bored to fit the centre spindle J, on which it revolves, supported in the centre by a hoop on the spindle J, and the edge c, resting on the top edge of the box L. By moving the board round, the spindle describes the proper form of mould preparatory to receiving the teeth.

The segment, or pattern T, is screwed to an iron angle bracket, and secured in the socket Z. The upper portion of the machine G Z is then brought in position over the mould and secured; the proper radius and position being ascertained, the pattern is lowered on the sand-bed already prepared by the strickling board.

Prior to this the number of teeth in the wheel intended to be moulded being found, the operator puts on the requisite change wheels O P, coinciding with the dividing wheel and the wheel to be

moulded. There is a list or table of changes sent with each machine, showing what wheels to use and how to place them, so that the time and trouble of the workman having to calculate these himself is dispensed with.

Say, for example, there is a wheel to make with fifty-five cogs, he would place them, according to the Table, in the following order:—

No. in Wheel to be made.	Handle Shaft.	Worm Shaft.	No. of turns per Tooth.
55	60	55	4

If the machine is heavy to work, through having a large box filled with sand, the relieving screw W is applied to the bottom of spindle J, and the machine will then work with ease.

The workman then proceeds with filling in between the two teeth in the pattern with sand, and, having rammed the sand to sufficient and uniform hardness, he raises the pattern from the sand by the hand-wheel H, working a pinion and rack which raises the vertical slide G to which the pattern is attached, and is held when raised by ratchet-wheel and retaining pall.

The requisite number of turns is then made with the handle N, and the pattern lowered into the mould by the hand-wheel H. On lowering the pattern in the sand for the second tooth, the operator should particularly notice, when lowering, whether the pattern tooth displaces or presses too hard on the sand tooth, and if it should do either, the wheel he is making is too small in diameter for the pitch and number of teeth intended, and it is necessary to make the wheel a little larger. This is very easily and readily accomplished by releasing the pillar D in the socket R, where it is secured whilst the moulding is in process, and then increasing the radius J T, Fig. 1, Plate LVI. If, on the contrary, it is found that a space is left between the pattern tooth and the sand tooth, on lowering the pattern for the second tooth, the wheel is too large, and the radius requires contracting. If the segment tooth only just touches the sand tooth without displacing the sand, the wheel is then the proper size. It always indicates, on making the second tooth, whether the mould is right, and if it is right, the workman proceeds to fill between the

two teeth of the pattern with sand as before, and so repeats the operation until the whole wheel is finished.

It is obvious that by the above process the moulder cannot err, for the first tooth will indicate any irregularity, whether in size of wheel or number of teeth.

Having filled in and rammed all the teeth required, the box L, containing the mould, can be removed from the machine, and placed on the foundry floor, and the machine is ready to receive another wheel. It is not necessary to case or even to finish the mould on the machine, but having removed the mould entirely from the machine to the floor, another workman can easily finish it by putting in the arm cores, centre core, and making the top part, and putting the boxes together, whilst some one accustomed to working the machine is proceeding with another wheel.

The top part or box does not require to be placed on the machine at all. It has a small hole bored through the centre, in which is fitted a spindle, and on this spindle the bracket V fits exactly as in the bottom part; the board does not require taking off the bracket, but both are inverted together, and the edges *d e* serve the same purpose in the top box that *a b c* did in the bottom box.

Having done this, and faced up and finished the moulds with charcoal or other powder in the usual way, the boxes are put together and the mould is ready for casting.

The use of gear-wheels to effect the regular movement of the table in wheel-moulding machines has been objected to by some, and in Bellington and Darbyshire's machine the use of geared wheels is done away with, and their place is taken by adapting to the table a perforated rim or ring of metal, called the dividing ring, which is placed above the periphery of the revolving table, and arranged to operate in conjunction with a locking device. The ring or rim is made to answer the same purpose as the dividing plate on a wheel-cutting machine, and to this end is perforated with a series of sets of holes in parallel lines around its periphery.

The table is held firmly in the required position by means of a screw pin suitably mounted, the end of which engages with the holes on the dividing ring, and after each tooth of the wheel has been moulded, the screw or pin may be withdrawn, until the next hole in the dividing ring is brought opposite to it, by the turning

of the table by means of the screw and worm-wheel, to be again held in position during the operation of moulding the next tooth. By this arrangement the revolving table itself is fastened directly and securely in position, at a point outside its largest diameter, thus giving to it a maximum of steadiness, which cannot be attained by any arrangement of geared wheels.

The cost of patterns for machine-wheel moulding is merely nominal, compared with the making of whole patterns, and if destroyed these are easily replaced. Again, the storage for whole patterns is generally very large and expensive, whereas if made by machine the storage will not exceed 10 to 20 per cent. of the room occupied by whole patterns. Whole patterns are very subject to get out of truth by variations of temperature, and it is very costly, even if at all practicable, to keep a room at one temperature. On the other hand, if the blocks for wheel moulding get out of truth, they are soon replaced at a very small cost, and wheels made by machinery are certainly more accurate than wheels made from a pattern.

In Whittaker's machine every arrangement is very convenient and compact, each machine being so constructed that a wheel can be made in it from 3 inches to 12 feet diameter. The workman is in an upright stationary position whilst at work, which enables him to work with more power, comfort, and less fatigue than if in a kneeling or stooping position, while all his sand, tools, and appliances, being close at hand, he need not move until he has finished his mould; while so far as can be, the whole of the dividing apparatus is in equilibrium when at work, and all the motions or slides, both vertical and horizontal, are in line with the base, so that the respective parts of the machine are true to each other.

CHAPTER XVI.

CHILL-CASTING.

Chill-casting converts into white iron the outer skin of a casting made from certain qualities of cast iron; the depth to which this alteration extends is capable of being regulated. This white cast iron is very hard, brittle, and crystalline, and scarcely differs either in chemical or physical properties from steel, except that it cannot be "tempered." In this case the whole, or nearly the whole, of the carbon contained in the iron is in a state of chemical combination with it; whilst in the darker irons most of the carbon is diffused throughout the mass in the form of small particles or scales.

If the cast iron contains a large proportion of manganese, the amount of combined carbon may be as much as 10 per cent., but ordinary pig iron seldom contains more than 5 per cent. of combined carbon. These particles of uncombined carbon must, whilst the metal is in a melted state, be combined with it, for being of a much less specific gravity, less than half, if they were floating about in separate particles, they would necessarily come to the surface of the metal. It is therefore assumed, that the separation of the particles of carbon takes place at the moment of solidification.

If a thin sheet of grey cast iron is rapidly cooled, it becomes whiter, that is to say, a larger proportion of its carbon is held in chemical combination. White cast iron may also be obtained from grey pig, by alternately melting and cooling it in the ordinary manner. When it is desired to obtain a white iron direct from the blast-furnace, the proportion of fuel is reduced below the amount usually allowed for the same quantity of ore and blast, if a good grey iron were required.

These facts explain the results which are obtained by the process of "chilling" a casting; where the skin of the casting is in contact with the "chill," it is, for a certain distance in, converted into a hard white iron, whilst the interior of the casting will

remain of the same general nature, as to colour and toughness, as the pig from which it was cast. The sudden cooling of the metal, prevents the combined carbon near the outer portion from separating, whereas the cooling of the inner portion of the metal being more gradual, allows it to resume its normal condition. The suspended particles of carbon which are held in the metal near the exterior of the casting, are supposed to be forced inwards into the interior, or still fluid portion, of the casting.

All, or nearly all, the carbon in the chilled portion of the casting is therefore in chemical combination with the metal, whilst that in the interior remains suspended as separate atoms or scales. Such is the generally accepted theory of chilled castings, which may indeed be open to objection; the practical result is, however, beyond any question.

A good example of the form of chill-moulds is shown in Fig. 1, Plate XLIX., which represents a chill-mould in which a railway wheel is cast. It consists of three boxes. The lower is a box of common round form, merely to hold the sand and give support to the centre core and the middle box. The upper box is of a similar form, also round. The middle box I I is a solid ring, cast of mottled iron, and bored out upon a turning lathe, giving its interior the reverse of the exact outer form of the rim of the wheel. This middle box ought to be at least as heavy as the wheel is to be after casting, and it is preferable if it has two or three times that weight. All the three boxes are joined by lugs and pins as usual, and the latter ought to fit well without being too tight. The chief difficulty in casting these chilled wheels, is to make the cast of a uniform strain to prevent the wheels from breaking, and wheels with spokes or arms are very liable to this.

At present, most of these wheels are cast with corrugated discs or plates; in this way the hub may be cast solid, and the wheel is not so liable to be subjected to an unequal strain in the metal as when cast with spokes. In such plate-wheels the whole space between the rim and the hub is filled by metal, which, however, in most cases, is not more than ¾ inch or 1 inch thick. The rim of a good wheel should be as hard as hardened steel at its periphery, but soft and grey in its central parts. The first requisite is more safely attained by having a heavy chill; but if the

chill is too heavy, the inner parts are apt to suffer from the cooling qualities of the chill. Success in this branch of founding depends very much on the quality of the iron of which the wheels are cast. Soon after casting such wheels it is advisable to open the mould, and remove the sand from the central portion, so as to make it cool faster; this precaution saves many castings, not only in this particular case, but in many other instances. Uniformity in cooling is as necessary to success as good moulding.

Chilled rollers are the most important examples of chilled castings. The mould for a chilled roller consists of three parts, as shown in Fig. 2, Plate XLIX. The lower box of iron or wood is filled with "new sand," or a strong composition of clay and sand, in which a wood pattern is moulded, which forms the coupling and the neck of the roller. The middle part of the mould is the chill, a heavy iron cylinder well bored. The upper part of the mould again consists of a box, but is higher than the lower box, so as to make room for the head in which the impurities of the iron, sullage, are to be gathered. The two boxes with their contents of sand must be well dried. In some establishments the two ends of the roller are moulded in loam, over the chill, to secure concentricity of roller and coupling; but this can be quite as safely arrived at by fitting the ears and pins of the boxes well to the chill. The chill is the important part in this mould: it ought to be at least three times as heavy as the roller which is to be cast in it, and provided with wrought-iron hoops to prevent its falling to pieces, for it will certainly crack if not made of very strong cast iron. The iron of which a chill is cast is to be strong, fine-grained, and not too grey. Grey iron is too bad a conductor of heat; it is liable to melt with the cast. Iron that makes a good roller will make a good chill. The face of the mould is blackened like any other mould, but the blackening must be stronger than in other cases, to resist more the abrasive motion of the fluid metal. The chill is blackened with a *thin coating* of very fine black-lead, mixed with the purest kind of clay; this coating is to be very thin, or it will scale off before it is of service.

The most important point in making chilled rollers is the mode of casting them, and the quality of iron used. To cast a roller, whether a chilled roller or any other, from above, would cause a

failure. All rollers must be cast from below. It is not sufficient to conduct the iron in below; there is a particular way in which the best roller may be cast, for almost every kind of iron. The general mode is shown in Fig. 2. In O is represented the cast-gate and channel, as it is seen from above. The gate is conducted to the lower journal of the roller, and its channel continues to a certain distance around it. It touches the mould in a tangential direction. In casting fluid metal in this gate the metal will assume a rotary motion around the axis of the roller, or the axis of the mould. This motion will carry all the heavy and pure iron towards the periphery, or the face of the mould, and the sullage will concentrate in the centre. It is a bad plan to lead the current of hot iron upon the chill, for it would burn a hole into it, and melt chill and roller in that place together. The gate must be in the lower box, in the sand or the loam mould. The quality of the melted iron modifies in some measure the form of the gate; stiff or cold iron requires a rapid circular motion, while fluid, thin iron must have less motion, or it is liable to adhere to the chill. The roller must be kept in the mould until perfectly cool, but the cooling may be accelerated by digging up the sand around the chill.

Many anvils, vices, and other articles are made of cast iron, mounted with steel; the welding together of steel and cast iron is not difficult, if the steel is not too refractory. This process will not succeed well with shear steel, and hardly with blistered steel; but it is easily performed with cast steel, by soldering it to cast iron by means of cast-iron filings and borax. The cast-steel plates to be welded to the faces of anvils, are generally from a half to five-eighths of an inch thick, and as wide as the face itself. These are ground or filed white on one side, and then covered on that side with a coating of calcined borax. The plate, with the borax on it, is heated gently until the borax melts, which covers it with a fusible transparent glaze. The plate in this condition is laid quite hot in the mould, which latter is made of dry and strong sand. The iron is poured in and rises from below; the steel plate being the lowest part of the mould, it will have the hottest iron. The heat to be given to the iron will depend in some measure on the quality of the steel; shear steel requires hotter iron than cast steel. The cast iron used for these purposes should be strong and

grey, but not too grey, or the union of the iron and steel is not strong. White cast iron will not answer in this case, partly because the casting would be too weak, but chiefly because the cast iron would fly or crack, in hardening the steel. The hardening is done under a considerable heat, with an access of water falling from an elevation of 10 feet or more.

As an instance of the very useful effect of chilling, may be cited the chilled cast-iron railway chairs, invented about twenty-five years ago, by E. A. Cowper, which speedily came into very general use. As the invention was simply a cheaper mode of producing better castings, it may be described in a very few words.

The importance of a railway chair being a strong, accurate, and sound casting, must at once be apparent to every mechanical man; as the failure of any one of these on a line of railway may be attended with most serious consequences.

On referring to Plate XLIX. it will be seen that A A, in Fig. 3, is the iron pattern; the inside of the pattern is not the shape of the intended chair, but the edges of the jaws are provided to receive cast-iron chill-plates, B and C, which are made so as to give the required form to the inside of the casting. These chill-plates are dotted in Fig. 3, and they are shown separately in Figs. 5 and 6, and in section in Fig. 6.

The pattern being placed in the moulding box, as shown in Fig. 3, the chill-plates were placed therein, one in contact with each jaw of the pattern. The sand was thrown into the box, and some of it rammed between the chill-plates, thus effectually securing their close contact with the pattern; the remainder of the sand was well rammed in until the box was full. The box and its contents were then turned upside down, in the usual way; the pattern slightly rapped, and afterwards withdrawn, by means of a screwed lifting pin; the chill-plates being left in the sand, formed a good guide to the pattern as it was withdrawn. The top box was put on, having previously been rammed up on another board, technically called an "odd-side board"; the melted metal was then poured in, and the casting was complete. As soon as the metal had thoroughly set, the casting was turned out, and the chill-plates dropped out of themselves. The finished chair is shown in Fig. 5, and D D are the two portions that are cast in the chills B and C.

The chill-plates were simply good castings, made from an iron pattern, not filed up, or fitted in any way, as the iron pattern of the chair was fitted to them, and the metal-chills being closely pressed by the sand against the metal pattern, great accuracy was obtained in the position of the chills; indeed, it was a very rare thing for the shape or inclination of the jaws of the chair to vary anything like $\frac{1}{32}$ of an inch.

It was found that the chill-plates stood exceedingly well, and in fact many hundred tons might be cast off one set of them; this was partly owing to their not being very thick, so that they soon got hot through, and did not strain or warp; the chairs were chilled just sufficiently to give a good, true face, but were not chilled-in very deep, in consequence of the chill-plates not being very thick, and the chairs themselves containing a large quantity of metal.

On this plan of casting chairs, boys only were employed for moulding, as the great ease and safety with which the pattern was withdrawn did away with the necessity of regular moulders being employed; thus considerably reducing the cost of the chairs.

"Chills" are almost always made of cast iron, in a few exceptional cases only is wrought iron substituted.

The greatest practical advantage to be derived from the process of chilling is in cases where a union of several opposite qualities is desired in the same casting. It would be difficult to over-estimate the value of the combination in a pair of chilled rolls, for instance, of an exterior as hard and dense as hard steel, capable of being turned or cut to a smooth polished surface, with an internal core, so to speak, of the best soft tough cast iron.

The chilled portion of the casting is of a higher specific gravity and harder than the interior, uniform in texture, and crystalline.

Even where the metal employed in the casting was originally a white iron, the chilled portion is found to be rather harder, and its crystalline formation more regular. Such a metal as white cast iron should not, however, be employed for chilled castings, as the interior would not be so tough and strong as it should be.

Dark grey irons are not at all adapted for the purposes of chilled castings, No. 1 Scotch pig being particularly unsuitable; when the right quality of iron cannot be obtained, it is sometimes

necessary to melt up a suitable proportion of hard white scrap cast iron, with the soft dark grey iron, which alone would scarcely chill at all.

Hard, tough, bright grey, or mottled pig, having small crystals and a good uniform texture, are well adapted for the purpose, provided they do not contain an excess of uncombined carbon; the presence of manganese in the pig iron, or the addition of a little spiegeleisen, improves the quality of the castings.

Where the shape and size of the casting are such that the mass of metal in the interior will long retain its heat, much of the effect of chilling is lost; the greater the proportion the chilled surface bears to the size of the casting, the more effectual the chilling will be. The depth to which the "chill" may be formed in castings admits of a certain amount of regulation, but there are also circumstances affecting the castings which are at times almost beyond control.

It is not always possible to obtain the right quality of iron; the size and shape of a casting cannot always be well adapted for chilling; or the chill-moulds may not be of sufficient depth of metal, to conduct away the heat from the molten metal with the necessary rapidity, to allow it to solidify without being again melted by the radiation of heat from the still molten metal in the interior.

Assuming a cylindrical casting of some 8 or 10 inches diameter, a depth of chill of at least 1 inch can be obtained, provided the metal employed is at all fit for the purpose, and with the iron best suited for chilling a much greater depth can be obtained, with proper care as to the moulds, &c. But in the great majority of cases 1 inch depth of chill is sufficient.

For castings that will have much surface wear, such as in rolling metal, or crushing minerals, allowance should be made in the depth of the chill for the removal of the exterior of the rolls, by their repeatedly being turned in the lathe, as their surfaces become worn or injured in use.

At the same time it must be remembered, that the greater the depth to which the chill is carried the more brittle is the casting. The chief strength of the casting is in its tough, unaltered, metal beneath the hard chilled surface.

In considering the advisability of the greater or less depth of

chill, therefore, estimate the extent to which the casting may be worn or turned before it becomes necessary to replace it.

Avoid chilling to a greater depth than necessary, especially in cases where strength is required in the castings, to resist transverse and other strains.

In casting large chilled rolls, the moulds for the ends and necks should be of dry sand, or loam, properly built up and connected with the iron chill for the roll itself. Or the iron chill for the ends and necks can be made much thinner and lighter in substance than that for the centre.

The mass of metal in the chill largely influences the depth of the chilled portion of a casting; it is necessary not only that it should be sufficient to reduce the temperature, in a few minutes, of the iron on the surface from, the temperature at which it is poured, say 2500° Fahr., to that of solidification, say about 1000°, when it is bright red in daylight, but also that it should be capable of absorbing the heat which will radiate from the interior of the casting, so as to prevent the solidified and chilled surface from being remelted by the radiation of internal heat.

Moisture in moulds is at all times dangerous, but when these are made of sand or loam, the danger is lessened to a certain extent by the porous material allowing of the escape of some of the pent-up gases and steam generated by the intense heat of the cast metal.

When, however, chill-moulds are used, the utmost precaution is required to have them absolutely dry for use.

This entire freedom from moisture could scarcely be obtained, still less preserved, in the warm damp air of a foundry, with perspiring workmen hurrying about; the steam and vapour would at once condense on the surface of an iron chill-mould, if it were brought *cold* into the shop. Consequently the chill is always heated to a considerable extent before pouring, a precaution which it is all the more necessary to observe when the chill is to be used in conjunction with sand or loam moulds. If this were not done, any dampness left in the sand or loam would probably be driven out, and at once condense on the surface of the chill, if that were not heated to a temperature considerably higher than that of the surrounding atmosphere.

The steam and gases which would be formed in a *damp* chill-mould, when the metal was poured, having no means of escape, would acquire tremendous expansive force, and would either burst the mould and send the liquid iron spirting about amongst the founders, or at least, ruin the casting and distort the mould.

It would appear that to heat the mould would impair its property of chilling the metal poured into it. Yet in practice it is not found to have this effect even when heated to 250° Fahr.

It is even asserted that a superior " chill " is obtained from a hot mould than from a cold one, *cæteris paribus*; it must be remembered that with a mould heated even to 250°, there is a large margin of difference between that temperature and that of the melted iron poured into it, and it is supposed that the chill has a greater tendency to conduct away heat from the metal cast in it, if it, the chill, be previously heated to about the temperature above named.

The heat given out by the cast metal, penetrates through the chill with extraordinary rapidity, and if the walls of the chill are not sufficiently thick to absorb the greater portion of the heat, considerable risk is run, that either the casting and the mould may fuse together in one solid mass, or that the effect of chilling may be neutralized, by the heat evolved from the central portion of the casting not being conducted away with sufficient rapidity. It may be assumed that cast iron expands slightly at the moment when it passes from the liquid to the solid form, such expansion, of course, tending to burst the mould.

To avoid these evils, the mass of the chill must be properly proportioned to the area of the portion of the casting which requires to be chilled, in relation to its entire bulk. In the case of a casting which has to be chilled over its entire surface, the weight of the chill-mould should be about three times that of the casting to be made from it, presuming the casting not to be of exceptionally large dimensions.

So varied, however, are the circumstances under which chill-moulds have to be employed, that experience is almost the only possible guide for their construction.

It is desirable not to make the chill-mould thicker than is necessary to enable it to carry off the amount of heat from the casting, from the fact that the thicker it is the more liable it is to

crack, from the severe strains put upon it by the expansion of its inner portion, when the great and sudden heat of the molten metal first comes upon it.

This expansion and the subsequent contraction in cooling cannot but be unequal, and the larger and thicker the chill-mould, the greater is the risk of a fracture.

In the preparation of large chills it is always advisable to shrink wrought-iron hoops round them where possible.

Certain results have to be decided upon beforehand, and the founder must use his utmost skill to attain them in the safest and most economical manner; the utmost that science can do to assist him consists in pointing out what evils to avoid, or how best to rectify the damages occasioned by want of judgment or scientific knowledge.

In a foundry where many chilled castings from different moulds have to be made, it will be apparent that it is to the interest of the founder not to make these chills any larger, or heavier, than is absolutely necessary to effect the desired result; cost of the metal in the moulds, and the amount of room required for their storage, sufficiently explain this.

There are several ways of finishing the interior surfaces of the chill mould before using it for casting.

For fine castings the mould must either be bored or machine planed, after which a coat of rust is allowed to form upon it; this is obtained either by wetting it for a few days with dilute hydrochloric acid, or with urine. The object of this coat of rust is to prevent the casting from adhering to the chill, but no "clay wash" must on any account be applied to the chill, as it would hinder its absorption of heat from the casting, and the rust itself must also be rubbed away for the same reason. When the surface of the chill has been thus prepared, and just previous to the casting, a thin even coating of blackwash, or black-lead, is applied. If, however, the surface of the chill has been tolerably well oxidized beforehand, this coating may be dispensed with, although, as a rule, founders prefer to apply some kind of wash before pouring.

As the iron which is best adapted for chilled castings does not flow very freely, it is necessary that it should be at a high temperature at the moment of pouring, more particularly as it will have

to part with its heat so rapidly on entering the mould, that it may solidify in irregular blotches, or clots, if it has not a sufficient store of surplus heat to keep the whole of the mass of metal in a liquid, or nearly liquid, state until the completion of the pouring.

For the same reason, the casting arrangements should be such, that the mould may be rapidly filled by a large stream or streams of metal, so directed, however, as to avoid, as far as possible, coming into continued and violent contact with the surface of the chill, which would thus soon become seriously damaged at such points of contact. The life of a chill-mould depends considerably upon the care with which it is used; if its surface becomes slightly damaged from the action of the molten metal, it may be patched up with a little loam, but wherever such patching occurs, the uniformity of the chill on the casting will be destroyed.

For fine work, or for castings where dimensions must be strictly adhered to, a very slight damage to the mould is fatal to it.

In many cases, however, when the mould is only slightly roughened in parts, it can be rebored, and made to do duty again. Of course, care must be taken not to remove a thicker skin of the mould than is necessary to get a smooth, even surface.

In the choice of the metal used for the chill-moulds, the founder has to consider whether he will be guided in his selection by economy or durability.

If the mould is likely to be one in great request, he should choose a hard, dense, close-grained pig iron from which to cast it, in fact, as we have before said, a metal very similar to that described as most suitable for the chill-castings themselves.

In other cases, however, not much care need be exercised in the selection of the metal for the chills, except that very dark Scotch iron, which is not at all suitable for the chilled castings, is also not well adapted for the chill-moulds.

It is impossible to lay down rules as to the exact dimensions of a chill-mould which is required to produce a certain-sized casting. In addition to allowance for the shrinkage of the casting on cooling, the sudden expansion of the mould itself, when the hot metal enters it, must be taken into account.

That part of the mould which first receives the flow of the hottest metal, not only expands most from having to bear the first

sudden increment of heat, but has also to bear the weight due to the head of metal afterwards poured in, until the casting has cooled and solidified sufficiently to relieve the mould of this pressure. Consequently, it may be inferred that the actual dimensions of a casting, will be that of the interior of the chill-mould, when it has been expanded to the extent due to the temperature of molten cast iron, when just on the point of solidification, minus the amount of subsequent contraction of the casting, during the process of cooling down to the temperature of the atmosphere.

The metal being poured into the chill, two actions immediately set in; the skin of the casting solidifies, and the metal in the interior commences to part with its heat, contracting away from the interior of the mould as it does so. The mould, at the same time absorbing heat, expands away from the exterior of the casting. The moment when the distance between the chill and the casting has reached its maximum, is, theoretically, the time when the casting should be removed from the mould. Experience, and the nature of the work in hand, must guide the moulder as to the safest time to withdraw his casting; if he attempts to do it too quickly, he may distort its shape, from its being as yet too hot and soft to bear the strain; if he leaves it too long, the chill-mould may have commenced to contract round the casting, and thus bind it hard and fast, besides having spoilt the chill surface, as before described. The higher the temperature of the cast iron when poured, the greater is the strain upon the chill.

The contraction of the casting during cooling depends less, perhaps, upon its absolute bulk than upon its form; and, as might be expected, a chilled casting contracts somewhat less in the cooling than an ordinary casting.

The principal elements which govern the amount of expansion in chill-moulds may be briefly stated as follows:—

Its internal capacity: the larger the quantity of molten metal it will have to contain, the greater the strains it will have to bear, from the longer sustained heat, and the greater pressure of the head of metal, before it has superficially solidified.

Its thickness: for large castings it is imperative that the chills should be thick in the walls, but with every increase of thickness the risk of cracking the chill is increased, owing to the tendency

of the heated inner portion to expand, being opposed by the rigidity of the outer and cooler portion.

Having withdrawn the casting from the mould, it should be allowed to get quite cold as soon as it possibly can by radiation. No artificial cooling, by cold water, &c., should be resorted to, as likely to distort or fracture the casting; and no further increase of hardness can be obtained in this manner.

Chilled cast iron and cast steel, similar as they are in many respects, have this important difference, that the one, cast iron, cannot be hardened by plunging hot into cold water, whilst the other, steel, can be hardened in that manner.

Avoid placing the casting in such an attitude, or in such a locality, as to expose it to undue strains, or to currents of air, or other circumstances likely to produce distortion or unequal cooling.

It has been mentioned that a chill-casting which has been allowed to cool down in the mould *too slowly*, owing to the chill not being sufficiently massive for its duty, or for other reasons, loses much of its chilled character, allowing a considerable portion of its contained carbon to pass into its former uncombined state, and the iron, instead of being hard and white, more nearly resembles the character of the pig from which it was originally cast.

Occasionally this quality is made serviceable, where it is convenient to use iron moulds, but where it is not desired that the resulting casting shall be hard or chilled. In such cases a pig iron may be selected which is of a bad chilling nature; or after the casting has been made in the chilled mould, it may be rendered soft and tough by being kept for several days at a low red heat.

Chills, when out of use, should be protected from rust by being greased and stacked under cover. Before being again used, the grease must be thoroughly removed, as it has a tendency to cause the casting to solder to the chill.

We conclude this chapter with a description of the American plan of making railway wheels, in which chilling in casting is employed to an extent unknown in any other industry.

The manufacture of chilled cast-iron railway wheels has now become a very important industry in the United States, upon whose railway system of 75,000 miles no other class of wheel is employed

to any great extent, at least for passenger and freight rolling stock. There are a large number of cast-iron wheel works in the country, varying in capacity of production from 450 down to 40 or 50 wheels per day, and such improvements have been introduced into the manufacture that, whereas some time since railway accidents arising from broken wheels were common, of late years such a mischance is almost unknown. One of the most important improvements in the process of manufacture, consists in mixing with the pig iron a certain proportion of Bessemer steel, crop ends of rails being most conveniently used for this purpose. This mixture, besides improving the chilling qualities of the wheel, adds greatly to its strength, and even allows of the use of anthracite in the place of charcoal pig iron.

At the works of Messrs. A. Whitney and Sons, of Philadelphia, one of the largest establishments for the manufacture of chilled wheels in the United States, the different processes have been brought to a high degree of perfection. The following is a brief description of the factory, and the manner in which the work is advanced from stage to stage. Of course the foundry is the most important portion of the whole works. It is a fine building, 450 feet long and 50 feet wide, with two lines of rails running down its whole length, except opposite the furnaces. The rails are laid to a gauge of about 10 feet, and upon them are placed twelve light travelling cranes, with a platform attached to the centre post, and upon which the man working the crane stands, and controls its movements, both in hauling the moulds and ladles, and in moving the crane from place to place upon the line, the crane being geared for travelling. The floor of the foundry is so laid out that there is room on either side of both pairs of rails for a row of moulds, and in the centre of the building is a path about 4 feet wide. Against one side of the building, and in the centre of its length, are five cupolas, three of 4 feet 6 inches internal diameter, and two smaller ones of 18 inches in diameter. The former are employed in melting the iron for the wheels, the latter chiefly for experimental purposes. The three cupolas are tapped into converging channels, all running into one large tipping reservoir, from which the small ladles are supplied. The blast to the cupolas is furnished by a vertical blowing engine, with two blowing cylinders, one at the

top of the machine and one at the bottom, with the steam cylinder between the two.

The mixing of the irons for the cupolas, is the most important and difficult operation in the whole course of the manufacture. Besides the steel scrap, nothing but charcoal pig iron is employed, and of this from twelve to twenty different kinds, all of the highest class, are used in varying proportions. But these mixtures have to be altered frequently, owing to irregularities in the nature of the metal, and daily tests are made with a view of ascertaining what changes, if any, have to be introduced into the next day's work. The proportions of the mixture being decided upon, the cupolas are charged, a ton of coal being first put in the bed of each furnace. The charge is then carefully loaded upon trucks, upon a weighing platform. Piles of the various pigs are placed in their proper order around the truck, and there is a drum upon the weighing machine, on which a sheet of paper is placed, and the weights of each different pig, in proper order, are written upon it. For instance, the workman commences with 250 lbs. of coal in his truck; he then places 125 lbs. of old steel rails, 125 lbs. of cinder pig, 350 lbs. of old wheels, and so on through the long list of charcoal pig irons employed, the old material being placed at the bottom of the furnace. The weighing platform is so arranged as to record the accumulating weights as the drum revolves, bringing before the workman the name and quantity of each successive ingredient which he takes from its respective heap before him. As soon as it is loaded, the truck is raised to the top of the cupola by an hydraulic lift. The moulds, when ready, are placed down the building in four rows, one on each side of the two lines of rail upon which the cranes run. The patterns used are almost all in iron, and the chills in the moulds are of cast iron. One workman can, on an average, mould ten wheels a day, but all failures in the casting, arising from any carelessness in moulding, are charged to him on a rapidly increasing scale.

This system has been found necessary, as the men are paid by the piece, and if only the price paid per wheel were deducted for the spoilt castings, a far higher average of failures would result, because the men would earn higher wages by working faster and more carelessly.

Before the metal in the cupola is ready to run, a charcoal fire is lighted in the receiver before spoken of, in order to warm it, and also that when filled, the metal may be covered with charcoal, and oxidation checked. In a similar manner the ladles, of which there are a very large number employed, have burning charcoal placed in them, and they are coated internally in the usual way. These ladles are cylindrical pots made of sheet iron, and mounted each on a pair of wheels for facility of transport. On the sides of each ladle are two sockets, into one of which the end of a long iron handle is inserted for hauling it along the floor. Also at each end of the axle is a square hole, into which is placed the end of a handle with forked ends. The ladle being run up to the receiver, the latter is tipped over by the gearing attached to it, and the ladle is charged; it is then brought along the floor to the crane, which takes hold of it, the two square-ended handles before mentioned are inserted in the holes in the axles, the ladle is raised, and the iron is poured into the mould. The chilled portion of the wheel sets almost as soon as it comes into contact with the chills, and in a very short time after the casting has been made the flasks are removed, the sand knocked away, and the red-hot wheel is placed on a trolly to be taken to the annealing pits. This process is one of the most important of the series. If the wheel be allowed to cool in the open air, severe internal strains are created, which will sometimes be sufficient to destroy the casting, and open-air cooling was the active cause of failure in the early periods of this class of wheel making.

The annealing ovens are placed at one end of the foundry, and below the floor, the top of the ovens being at that level. Besides these ovens of very large diameters for extra-sized wheels, chilled tyres, &c., there are forty-eight pits ranged in six rows of eight each. These rows are divided into pairs, each pair of sixteen pits being devoted to the reception of one day's production, the period required for annealing being three days. By this arrangement, when the last two rows of ovens are charged, the first two rows can be emptied and refilled, so that the work proceeds without interruption, and in regular rotation. Two hydraulic cranes, with the booms revolving upon a fixed post, are placed upon the floor, and command the whole area occupied by the ovens. The boom

of each crane is made double, and upon it runs to and fro a small carriage, from which hangs the chain, carrying at the lower end the hooks by which the wheels are handled. This attachment consists of three arms, with flattened ends turned over so as to grip the wheel. The upper ends of these arms are hinged together, and as they tend always to fall inward, they hold the wheel tightly, but by moving a single attachment the arms are thrown outward when it is desired to release the wheel. The motion of the cranes is controlled by one man, fixed stops being provided on the guiding apparatus, so that when the crane is adjusted for filling one oven, it remains in that position till it is thrown over to the next.

The ovens or annealing pits are cylinders of sheet iron $\frac{1}{8}$ inch thick, about 66 inches in diameter, and of sufficient depth to contain easily eighteen wheels with cast-iron distance pieces between them, They are lined with brickwork, and being of considerable depth, they descend into a lower floor. The lower parts are inclosed in a large rectangular chamber, one for each set of ovens. Within this chamber, and for a short distance above it, firebrick is used instead of ordinary brickwork as in the upper portions, and within the cylinder a circular foundation of brickwork is set, upon which are placed the wheels on being lowered by the crane. The whole of this weight then is transferred direct to the foundation of the building. At the end of each of the three rectangular chambers already mentioned is a furnace, and each chamber is divided down the whole of its length by a perforated flue; through these perforations the heat from the furnace passes and enters the lower ends of the ovens. These furnaces are required to prevent the too sudden cooling of the castings, but only $\frac{1}{4}$ ton of coal is burned for each full day's production. Flues leading to the chimney carry off the heated gases from the upper part of the ovens, and so the process of cooling is thus very gradually carried on, until at the end of three days the wheels are ready for removal. The three large annealing pits mentioned above are somewhat differently arranged. To save room, they are not carried down so low as the other ovens, but terminate at a height of about 7 feet above the floor, each being supported upon a central column. When they are used, a fire is lighted in the bottom of each pit, the wheels are placed in and covered over, and the oven is allowed to cool gradually.

On being removed from the pit the wheels are taken into the cleaning and testing room. Here the sand is removed, and the wheels tested by hammering under a sledge, as well as by a small hammer, while the tread is cut at intervals by a chisel. The heavy blows to which the wheel is subjected never fail in detecting faults when such exist, and when they are discovered the wheel is removed to be broken up. About 10 per cent. of the whole production is rejected, but occasionally this proportion is very much higher.

In order to keep the quality of the wheels to the desired standard, a large number of test pieces are cast every day and submitted to examination. By this means an accurate knowledge of the nature of the wheels, the character of the chill, and other points are obtained; the data are carefully recorded, and if the tests are satisfactory the wheels corresponding to the test piece are delivered into stock. If not, they are returned to be broken up. The sound wheels finally are taken to the machine shop, where they are bored, and if desired fitted with their axles. The tools, therefore, in this shop are few in number, consisting of three boring machines, a press for forcing the wheels on or for drawing them off the axles, and a number of lathes.

The capacity of Whitney and Co.'s foundry is 250 wheels per day.

The average life of a chilled cast-iron wheel of first-class quality is asserted to be 50,000 miles for passenger, and 100,000 miles for goods traffic. This is a high average, and probably many wheels fail before they attain this mileage. The common mode of failure is a breaking away of the surface of the tread in spots, until large portions of the chill become pitted in shallow holes. The exact cause of this failure has not yet been ascertained. In some cases such wheels are turned down to a smooth surface, and again placed in service.

CHAPTER XVII.

MALLEABLE CAST IRON; CASE-HARDENING.

The manufacture of what are known as "malleable castings" consists in obtaining a tough, soft, flexible material, resembling wrought iron, from white brittle castings, by what is known as the cementation process. Some means of arriving at the same result appear to have been known to iron workers in the Middle Ages, as there are numerous examples of malleable castings to be found in old buildings, but Samuel Lucas, of Sheffield, appears to have been the pioneer in modern times of this important branch of the iron trade. He obtained a patent in 1804 "For a method of separating the impurities from crude or cast iron without fusing or melting it, and of rendering the same malleable and proper for several purposes for which forged or rolled iron is now used; and also by the same method of improving articles manufactured of cast iron, and thereby rendering cast or crude iron applicable to a variety of new and useful purposes."

A short description of the process is thus given in 'The Repertory of Arts':—"The pig or cast iron being first made or cast into the form most convenient for the purpose for which it is intended, is to be put into a steel-converting or other proper furnace, together with a suitable quantity of ironstone, iron ore, some of the metallic oxides, lime, or any combination of these, previously reduced to powder, or with any other substance capable of combining with or absorbing the carbon of the crude iron. A degree of heat is to be then applied, so intense as to effect a union of the carbon of the cast iron with the substance made use of, and continued so long a time as shall be found necessary to make the cast iron either partially or perfectly malleable, according to the purpose for which it is intended. If the casting is required to be perfectly malleable, from one-half to two-thirds of its weight of the other substances will be

found necessary, but a much less quantity will suffice if partial malleability only is desired."

Towards the close of the process the heat must be very great. The duration of the heat, its degree, and the proportion of the substances to be employed, depend upon a variety of circumstances, "a knowledge of which," the patentee remarks, "can only be obtained by experience." For small articles the intensity and duration of the heat required to produce the malleability are less than for large castings. Such articles may be arranged in alternate layers with the other substances, separated, however, from actual contact by an intervening thin layer of sand.

Malleable cast iron will take a certain amount of polish under the action of emery and rouge, but not so good a polish as cast steel. In the lathe it works about as easily as wrought iron, but the tool blunts rather more rapidly. Thin pieces may be bent double when cold, but seldom can be bent back again without breaking. It can be forged to a certain extent when at a moderate red heat, but if heated much beyond that, it breaks in pieces under the hammer.

Two pieces of malleable cast iron may be burnt together at a temperature approaching fusion; or can be brazed to either wrought iron or steel with hard solder. If plunged red hot into water it is hardened, but to an uncertain and variable extent. Malleable cast iron is very soft, flexible, and far from brittle; it will only weld with difficulty, if at all; its fracture is dull, grey, and uniform. Specific gravity about equal to cast iron, if anything a trifle less.

Most authors say it is decarburization by which cast iron is malleableized in this process, but Mallet doubts this, and remarks that by annealing white brittle cast iron either in hæmatite, chalk, or sand, we obtain not so much a chemical change as a molecular change in its constituent particles.

The uses for malleable castings are daily extending, and there is scarcely a trade connected with domestic or manufacturing appliances which does not largely employ this valuable material, so superior to ordinary cast iron for most purposes. One of the most important applications of malleable iron is for the manufacture of toothed wheels for machinery, but the process cannot be relied on

to produce a really tough metal when the castings are very large, or have any considerable portions exceeding 2 inches in thickness. Certain qualities of cast iron may be rendered stronger and tougher by the addition, in the cupola, of a proportion of wrought iron, steel, or manganese; this metal is said to be better adapted for spur-wheels, than common cast iron.

The general routine of the process of making malleable castings is as follows:—The pig iron is melted in and run from clay crucibles into green or dry sand moulds, and where the articles are small, snap flasks are much used. The castings are removed from the moulds, and cleared from sand by brushing, by shaking in a rattle-barrel, or by similar means, and are then placed in cast-iron "saggers," with alternate layers of powdered red hæmatite ore, or with fine iron scales from the rolling mills. The saggers are then placed in the annealing furnace, where they are exposed to a gradually increasing degree of heat, until a full red heat is attained, after which they are allowed to cool down. The articles are then removed from the saggers, cleaned from the hæmatite powder, and so far as rendering them "malleable" is concerned, the process is completed.

The pig iron employed is almost invariably hæmatite; for large castings white hæmatite pig is selected, for small articles mottled pig. In England, Cumberland iron and irons from the Barrow Steel and Iron Company's Works are largely employed; while in America they prefer the best brands of cold-blast charcoal mottled irons, Nos. 4 and 5 Baltimore, or 5 and 6 Chicago, having an excellent reputation.

It is essential that the pig shall be white or mottled, not grey, and it is not uncommon to melt up a quantity of scrap, such as wasters, gates, and fins of white iron.

The clay crucibles in which the iron is melted are frequently made in the foundry; they are heated in several ways. In the case of large works, the Siemens gas-regenerative furnace is by far the best and most economical apparatus for melting in the crucibles, with which any desirable temperature can be obtained and regulated.

In this arrangement the crucibles are placed in a chamber, through which the ignited flame of gas and air passes over from the regenerator on one side of the furnace, towards the other,

where the remaining heat is taken up by the mass of fire-brick in the regenerator on that side. When the bricks in the first side of the regenerator have so far cooled down, that the gases do not fully inflame, the currents are reversed, and the air and gas are sent through the second, and now hottest, part of the furnace, the flame passing amongst the crucibles, and then reheating the first part of the regenerator, before passing away to the chimney flue.

When the articles to be cast are of a greater weight than, say, half a hundredweight, the pig is occasionally melted by coke in a small cupola, with fan-blast.

But the most usual form of furnace for ordinary work is the common air-furnace, with the grate and ash-pit below the crucible.

The boxes for the moulds are generally of cast iron; the moulds are formed of green or dry sand; that obtained from the new red sandstone is much used in England. This is a fine sand, of uniform grain, containing sufficient clay to cause it to work stiffly without any further admixture of clay. For very small work an excellent sand is obtained from Moxeley, near Birmingham, which is used without any charcoal; for larger work it is mixed with a proportion of powdered charcoal. There is also a good sand to be obtained from Rowsley, which, however, requires to be ground and screened before use.

In making the moulds for small articles in malleable iron, the runners are nearly always formed in the parting of the box, and both gates and runners are made as small as possible; flat, wide, and thin in cross-section. This is rendered necessary from the rapidity with which the metal cools, causing it to contract, and frequently to break off from the gates very quickly after the metal is poured.

For small articles it is not usual to face the moulds, as the metal must be poured at such a high temperature that facing would be useless; the small stream of metal, however, is so rapidly cooled in its passage through the mould, that it is not indispensable for the sand to be as infusible as it would be required with larger work.

The amount of contraction appears to be greater with these castings than with soft cast iron; they are very brittle, and should have a white crystalline fracture.

For small work parting sand is not used for the boxes, but fine

dry powdered clay; the moulds are generally dried in small stoves, heated by coke, or the waste heat from a crucible furnace. This operation takes but a short time. The castings must be raked, or if very small, sifted, out of the sand when cool, and must then be cleaned from sand, which can be easily effected, if the articles are of a convenient shape, by rolling them over each other in a barrel called a tumbler or rattle-barrel; or they can be cleaned by hand, or immersed in a bath of dilute sulphuric acid, after which they must be washed and dried. Runners or fins on the castings have to be *chipped* off with the edge of a steel chisel, as they cannot be filed away.

The annealing pots are cylinders, preferably of cast iron, about 12 inches diameter, by 16 inches high, with loose covers dropping in. This size is well adapted for small articles, but for special purposes the pots are frequently made of wrought-iron plates, which, however, will not stand the action of the annealing furnace more than three or four times, whilst the cast-iron pots will frequently serve for twenty annealings.

The material most frequently used for filling in the pots between the tiers of articles to be annealed, is red hæmatite ore, which is ground and sifted through a mesh of about an eighth of an inch, the powder not being used, or if iron scales are employed, care must be exercised to keep them free from dirt.

A certain quantity of fresh hæmatite, or iron scale, should always be added, to any that has before been used, without the latter has been newly ground up.

A layer of hæmatite, or iron scale, is spread over the bottom of the pot; on this the first row of castings are placed, each article perfectly isolated and imbedded in the hæmatite, then another layer of about half an inch of the hæmatite, then another row of castings, and so on until the pot is nearly full, when it is covered up nearly flush with hæmatite, upon which the cover is placed, and the pot is ready for the furnace.

In arranging the pots in the furnace, those which contain the largest work should be placed in the hottest part, and the pots should be marked or numbered, as a guide to the furnace man as to the amount and duration of the heat to which they should be subjected.

As before mentioned, the duration of the operation depends upon the size of the articles, but the usual plan is to heat the pots gradually to a bright red, at which temperature they must be kept as uniformly as possible from sixty to eighty, or even ninety hours, after which they are allowed to cool down gradually in the furnace for about thirty hours; they are then removed, and allowed to get quite cold before being emptied.

If the castings are removed from the pots before they are cool, they will not have such a good appearance as if allowed to cool in the pots. It is advisable to avoid placing large and small articles in the same pot, as they require to be in the furnace different periods, and the large articles may require to be annealed a second time if this is done.

After the castings have been properly annealed, they are covered with a film of oxide of different colours. These various colours of the oxide are a sign of good malleables. This adherent oxide is removed from the casting by another passage through the rattle-barrel, and the process of malleable iron making is finished.

In every heat or annealing operation, the scales part with some of their oxidizing qualities, and before they are again used they must be pickled and reoxidized. This is done by wetting them with a solution of sal-ammoniac and water, and mixing and drying them until they are thoroughly rusted, when they are again ready for use.

Case-hardening is a means of superficially hardening castings, and is effected by placing the articles that are to be hardened, after being finished, but not polished, into an iron box, between layers of animal charcoal, such as hoofs, horns, leather, or skins, burned and pulverized, taking care that each article is completely enveloped in the charcoal. When the process is conducted on a large scale a proper furnace is used. The materials consist of 90 per cent. of charcoal, the remainder being either carbonate of potash or of lime. The articles are packed in this material in the usual manner, any parts which it is desired to prevent becoming case-hardened, being previously coated with clay. The box is made tight with a lute of equal parts of clay and sand, placed in the fire, and kept at a light red heat for such a time as will give the

required depth of case-hardening, which may vary from half an hour to two hours or longer. The articles are then plunged into water, but if they are liable to buckle out of shape, they should be carefully put into the water, end first.

To case-harden cast iron quickly, bring to a red heat, then roll it in a mixture of equal parts of powdered saltpetre, sal-ammoniac, and prussiate of potash. Then plunge it into a bath containing 4 ounces sal-ammoniac and 2 ounces prussiate of potash per gallon of water.

Another plan is to heat the articles, after polishing, to a bright red, rub the surface over with prussiate of potash, allow them to cool to dull red, and immerse them in water.

The following mixtures are also employed in some shops: (*a*) 3 prussiate of potash to 1 sal-ammoniac; or (*b*) 2 sal-ammoniac, 2 bone-dust, and 1 of prussiate of potash.

Where a proper furnace is employed some such form as that shown on Plate L. will be found of service. This plate shows Dodd's case-hardening furnace. Fig. 1 is a longitudinal section, Fig. 2 a section through one of the retorts, and Figs. 3 and 4 are a transverse section and a sectional plan. The advantages claimed for this construction of furnace are that it maintains a uniform heat in all parts of the retorts, and avoids any injurious effects from sudden cooling, when the latter are withdrawn.

The flame from the fireplace passes under and all round the sides of the retorts, then into and along the arched chamber over the retorts, from which openings lead into the side flues which communicate with the chimney.

The principal dimensions for such a furnace as that here shown would be for the flues between retorts 12 inches by 6 inches, for flues on outer sides of retorts 6 inches by 6 inches, flues under retorts 7 inches by 6 inches. The span of the arched chamber 6 feet 4 inches, with a rise of 18 inches. It is placed in communication with the two side flues by four openings, each 6 inches square. The retorts are each 9 feet long, by 1 foot 4 inches wide, by 1 foot 3 inches high.

The fire-grate, 9 feet long by 12 inches wide, is placed about a foot below the level of the bottoms of the flues, passing under

the retorts. In several parts of the furnace hollows are left in the walls, these are filled with sand, which tends to prevent sudden alterations in temperature.

The length of time the articles are allowed to remain in the furnace varies according to their size and the depth to which the steeling is desired to penetrate. As there are two retorts they can be charged and drawn alternately.

CHAPTER XVIII.

CASTING ON TO OTHER METALS.

It is occasionally desired to unite other metals by means of cast iron, or to fix ornamental castings on to light work, made of wrought iron or steel.

Such a process cannot be practised with cast iron upon any of the other useful metals than cast iron, wrought iron, or steel, as all the other metals, at all commonly used, have melting points so much below that of cast iron, that they would not bear coming in contact with liquid cast iron.

Sometimes non-metallic substances, such as grindstones, &c., are held in shape by rings or bands of iron cast round them.

When iron is cast upon or around solid wrought iron or steel, certain changes are brought about upon these metals. The cast iron, when thus brought into contact with the comparatively cool surface of the solid wrought iron or steel, will of course be "chilled" at and around all points of contact. It will therefore be harder, more brittle, and much less tough in those parts; and this result will occur wherever liquid cast iron comes in contact with either solid cast iron, or wrought iron, or steel.

When wrought iron is employed it is found to undergo a certain amount of deterioration, both in toughness and cohesion, becoming of less value for structural purposes where those qualities are required. Steel suffers in the same manner, but to a much less extent. A bar of cast iron cast round a core of wrought iron will be found little, if anything, stronger than a simple bar of cast iron of the same size. Consequently, where the full strength and toughness of these metals are required, "casting-on" should be avoided, and especially in any work which will be exposed to sudden shocks, or varying strains.

But a very large number of useful and ornamental articles, requiring little absolute strength, can be most readily produced by

the process of casting on, such as hand-railings, window frames, panels, hat and umbrella stands, bedsteads, or ornamental gates.

One well-known application of this process is Moline's invention for the combination of wrought and cast iron in the manufacture of window frames. The sash-bars are formed of wrought iron, rolled of any light and convenient section, suited to receive glass: these bars are united by ornamental cast-iron bosses. The mode of arrangement is illustrated in Figs. 3 to 7, Plate XXX.

An iron pattern is first made, from which a sand mould is obtained, the wrought-iron bars are cut to the required lengths, and placed in the mould, with their ends nearly touching; over these ends the mould of the boss is placed, which must be sufficiently large to cover them, so that when cast on, the bosses shall firmly unite the wrought-iron bars. These windows can be readily made of any usual size or shape, and are easily fixed. They are light in appearance, and combine the strength of wrought iron with the ornamental character, which can be easily obtained by the addition of cast-iron flowers, scrolls, armorial bearings, or other ornaments.

For ornamenting wrought-iron railings, two ways of applying cast iron may be mentioned. Either the wrought-iron bars may be placed in the moulds, and the ornaments cast round their ends, or the ornaments may be cast in green-sand moulds, cored out to fit the wrought-iron bars, on to which they are afterwards fixed by an alloy of zinc and lead. Lead alone is to be avoided, as it sets up a galvanic action, and assists the formation of rust.

In designing cast-iron railings it will be well to adopt outlines in which the metal will not be unfairly strained, by the union of very light and heavy pieces in the same casting. Discard all very fine ornamental work for streets where there is much traffic, as accident or mischief will very shortly spoil the beauty of the work, which cannot be repaired. Ornamental cast-iron work of a fine intricate character is only in place where it can be seen to advantage, and is not exposed to violence.

The hat and umbrella stands cast by the Carron Iron Foundry, and the architectural appliances cast by Walter Macfarlane and Co., of Glasgow, are good examples of ornament in the right place.

Exposed to the air in large cities, cast-iron railings are much more durable than those of wrought iron.

If cast-iron chill-moulds are used for the ornamental castings, the ornaments will naturally be rather brittle; in most cases this will be found of little consequence, but where it is desired to avoid brittleness, the work can be placed in an annealing oven, when the cast iron will be made into malleable cast iron, without prejudicially affecting the wrought iron, if any is used in conjunction with the cast iron, as is frequently the case.

"Burning-on" is also occasionally practised, for the purpose of ornamenting wrought iron with scrolls, volutes, or twisted forms. Loam moulds are made, and when thoroughly dried, are applied to that portion of the wrought iron which it is wished to burn on to; cast iron is then poured through the moulds until the wrought iron is brought to a welding heat; pouring is then ceased, and the cast iron, when cooled down, is found firmly affixed to the wrought iron.

For ornamental cast-iron railings which are designed with comparatively heavy pilasters and bars, having the intervals between them filled in with light ornamental work, the two should not be cast at one and the same time, otherwise the light work will be almost certain to break away from the heavy, owing to the unequal contraction in cooling. The ornamental work should be cast first, of fine, soft, fluid iron, and be provided with small fitting pieces or lugs, at convenient points for fixing to the heavy bars or uprights.

Coat these lugs on the fine work with clay and blackwash, place it in a sand mould, and cast the heavy work round it. By so doing the iron will not be liable to fracture from unequal contraction and expansion; but there is another danger to apprehend, which shows that very ornamental fine work, which is usually costly, should be avoided in all public thoroughfares.

An example of handsome cast-iron work may be seen in London on the Thames Embankment, but the ornamentation is so small, that its details can only be seen on a close inspection; the cast iron is chilled, and very brittle, and mischievous boys, as they pass along, knock off large pieces, so that from Waterloo Bridge to Charing Cross Bridge there are few bays which are not seriously damaged.

Burning-on is sometimes of service in repairing a broken or

damaged casting, but the process is neither applicable to fine delicate work, nor to cases where the size and shape of the original casting must be strictly preserved, as in a cast-iron wheel, which would probably be twisted out of shape, by the expansion and subsequent contraction of the metal, during the operation of burning-on.

But a piece of machine framing, the necks of rolls, or a standard which has been broken or found defective, may be repaired as follows; first cut away the defective parts down to the sound metal, build a coke fire round the part of the casting which is to be repaired, until it is brought to a bright red heat, then dust over the surface of the cut metal with powdered glass or borax. Then apply a hollow loam mould of the desired part to the casting, properly secured in position, and provided with a hole for the exit of the metal. Pour very hot liquid cast iron into the mould, and allow it to flow away until the cut surface of the original metal of the casting can be felt with an iron bar to have become soft and pasty by contact with the hot liquid iron. Then stop the exit hole, and allow the metal in the mould to set. If the operation has been properly performed, the casting should ring, when struck, with the same sound as a single good casting, thus showing that the old and new metal are perfectly united.

Where portions of large castings require to be removed for this burning-on process, the easiest mode of doing it is, to cut the casting whilst at a cherry-red heat, with a rapidly revolving circular saw, such as is used for cutting off the "crop-ends" of rolled rails.

Cast iron may also be bent to a considerable extent with safety at a cherry-red heat, which quality is occasionally of service, in remedying variations from the desired shape, arising from contraction in cooling. The bench or surface on which such bending is to be performed must be constructed of non-conducting material, such as baked fire-clay, otherwise the iron will part with its heat too suddenly, and break rather than bend.

Holes occasionally occur on the surface of a casting, which, although not of sufficient importance to make it advisable to reject and break up the casting, are unsightly. Liquid cast iron may be poured into such holes, the superfluous metal being removed by an iron straightedge. It is usually preferred, however, to fill up

these cavities with an alloy having a similar appearance to the cast iron, but being much more fusible. One such alloy consists of antimony 69, copper 16, tin 2, melted together, to which add afterwards, lead 13 parts, by weight; another is, antimony 65, copper 16, lead 13 parts, by weight, prepared in the same way.

CHAPTER XIX.

DRYING STOVES.

THE stove or chamber required for drying the sand, or loam, moulds and cores, should, if possible, be built contiguous to the moulding shop, with lines of railway running into it through openings in the partition wall.

The cores and moulds to be dried, being placed upon iron trucks, can be run into the stove, from various parts of the moulding shop, and when dry, should be withdrawn from the other side ready to be placed in the pit for pouring. In this way the continual flow of work is kept in one direction, progressing towards completion, and time and labour are much economized, especially where large heavy work is in hand.

The stoves are generally built in sound brickwork, and of such shape and dimensions as are required for the kind of work to be executed, and are provided with appliances for entering and withdrawing, or shifting the position of the articles to be dried. The walls, especially if exposed to outside air, should be built double, with an air-space between them.

In some cases it is possible so to arrange the stoves that their heat shall be greater towards that end where the cores are withdrawn, as in the case of a pipe foundry, where the cores are tolerably uniform in bulk, and will therefore dry in regular rotation, so that the wet cores on entering can be placed in the coolest part, and be gradually advanced as they dry, to the hottest part, previous to being withdrawn. In the majority of foundries, however, such a systematic course cannot be adopted, owing to the varying bulk of the cores and moulds to be dried, and the necessity that exists for the men to be able to get at them to

apply the *blackwash*, which is generally done by men within the stove.

The stoves are sometimes built with cast-iron floors, without any rails, the trucks are then wheeled along the rails to the entrance of the stove, but when in the stove they run upon the flanges of the wheels, which are made rather broader than usual to give them a good bearing surface. This plan considerably lightens the labour of the men, as the loaded trucks can thus be more easily moved from one part of the stove to another, than when obliged to follow the line of rails.

During the drying the cores and moulds generally have to receive several coats of blackwash, which consists of fine coal-dust and a little clay mixed with water to a creamy consistence, and applied with a brush.

If the stove is required to be of any considerable length, it is desirable to provide it with sliding iron partitions, by which it can, when necessary, be divided into compartments, with doors to each, so that the articles in any one part of the stove can be made accessible, without delaying the drying of the others. During the time that any one compartment is thus separated from the remainder, the current of heated air must be diverted past it, by means of a flue provided with valves for regulating the flow of the air.

An ordinary drying stove consists of a simple brick chamber, with large plate-iron doors at one end, which can be thrown wide open. The three sides are built in 9-inch brickwork. In one of the sides is a fireplace, which can be supplied with fuel from the outside of the stove, and may be shut off by a closely fitting iron door. In the opposite side of the fireplace is a flue leading to the chimney; this flue is placed low down. An arched brickwork dome covers the chamber. Iron shelves are arranged along the walls for drying small cores and boxes on. A line of rails which is within the sweep of a crane, leads into the stove, and any heavy mould which is to be dried may be laid upon a car running on this track, and both car and mould are shoved into the stove, the doors closed, and fire put in the furnace. The size of a drying stove is varied according to the size of the castings commonly made in a foundry. A stove of 12 feet in all directions, and

7 feet high, is a good-sized stove. When there is no occasion for employing a large stove, a small one is selected by preference, because it works faster, and with less fuel.

One plan of drying moulds, which is in use in the North, consists in forcing air through mains below the foundry floor, and having openings in the bottom of each pit, within which the moulds are placed. Over the opening into each pit is placed an iron basket full of burning coke, and over the top of the pit a cover of plate iron is let down, having a small opening for the escape of the heated air. By thus blowing heated air amongst the moulds they are quickly dried.

The amount of fuel which is generally consumed in the process of drying the cores and moulds, is far in excess of its theoretical duty. This arises partly from defective construction of the stoves, and partly from inefficient firing, and want of control over the ingress and egress of air.

The work to be done is usually very small in comparison with the weight of coke or coal consumed; a slow current of warm air, not exceeding 450° or at most 500° Fahr., has to be kept constantly passing through the stoves, and carrying off the vapour from the wet moulds. Assuming that 1 lb. of coal should evaporate 15 lbs. of water, at the pressure of the atmosphere, and that 1 cubic foot of wet loam contains about 30 lbs. of water, 2 lbs. of coal would be sufficient to effect the drying of 1 cubic foot of wet loam.

Such a result has probably never been attained, certainly not by the old-fashioned modes of firing, one of which consists in having a large open fire in the interior of the stove, the other in having an external furnace, the products of combustion from which pass into and through the stove.

In addition to the careful attention required in regulating the temperature, it is necessary to force the current of warm air through the stove, at such a speed as shall be sufficient to keep the atmosphere in the stove from becoming saturated with vapour, at the same time avoiding too tearing a draught of the heated air.

The evils which arise from defective regulation either of the temperature or of the speed of the current, will be gathered from a consideration of the following points:—

In order to dry any material in a confined space, it is necessary

not only to heat the air in that space, but to change it before it becomes saturated with moisture, otherwise the material is simply steamed, not dried.

This fact is shown by Dalton's experiments, which proved that by having a brisk current of air 36 grains of water per minute could be carried off, from the same surface that only gave off about 22 grains of water in a still atmosphere.

It would appear, therefore, that a high temperature with a brisk current are the most favourable conditions for drying, but with regard to cores and moulds, the limit of both these powers is soon reached. Supposing a low temperature is adopted with a very rapid current of air, the surfaces of the loam are very liable to crack; whilst if the low temperature is used with a slow current, the loam in drying gradually gets so dense and consolidated as to lead to a probable failure in the casting from "blowing."

If, on the other hand, the temperature is forced beyond 500° Fahr. with a slow current, the moulds and cores dry unequally, and the steam which is generated splits off pieces, and thus spoils the cores and moulds, besides destroying the fibrous qualities of the hay-bands, tow, or horse-dung used for binding the loam, and other materials used in their construction.

The speed of the current must be regulated by the foreman in charge of the stove, to suit the work being dried, and observations upon the amount and rapidity of the evaporation going on in the stove should be frequently made, and carefully noted.

The weight of water held in suspension by still air increases rapidly with the increase of temperature; thus with the barometer at 30 inches, and the temperature 32° Fahr., 1 cubic foot of air is saturated with 2·3 grains of water; at 100° Fahr. it is saturated with 19 grains; at 150° Fahr. it is saturated with 70·5 grains; whilst at 200° Fahr. it will hold in suspension as much as 204 grains of water; but in order to remove this vapour from the stove, a current of dry air must be kept constantly passing through it.

By means of a self-registering thermometer, the maximum and minimum temperatures during the day can be ascertained; the actual rate of evaporation can be arrived at by a very simple contrivance of a porous earthen jar, provided with a glass tube,

closely fitted into the top, and tightly closed with a cork. Having filled the jar and tube with water, at the temperature of the stove, and corked it up, the loss of water from evaporation through the porous jar will be readily ascertained.

When the stove has been at work a few days, and the drying has been regulated by the foreman, he will have noted the temperatures employed, and by taking the number of inches of water that have been evaporated in the time from the porous jar, he will know what has been its loss of water per hour.

If the result of the drying has been satisfactory, he will be able to give instructions to the workmen to maintain the temperature at a certain degree, and the current of air at a certain velocity, as indicated by the thermometer and the evaporating jar.

The jar must be refilled with water at certain times, and should be protected by a screen from dust and draughts of air.

For heating the stove, a regenerative fire-brick furnace has many advantages. It is easily regulated, can be heated with refuse coal, and the heated air is delivered into the stove much more free from dirt and soot, than when the stove is simply used as part of a flue for the products of combustion from the heating fire to pass through, on their way to the chimney.

The regenerative furnace will consist of two chambers full of good refractory fire-brick; one of these chambers whilst being heated by the fire will be in communication with the chimney, and will be shut off from any communication with the drying stove; the other chamber, having its fire-brick contents thoroughly hot, will be giving off its heat, to the volume of air passing through it on its way to the drying stove, and will be closed to the chimney flue, which should be arranged to pass from these fire-brick chambers under the stove to the chimney. When the first chamber is getting cool, the current of cold air will be turned off from it, the chimney flue opened, and fire or gas applied to reheat it; whilst the second chamber will take its place to heat the air for the stove.

In addition to taking off the products of combustion from the regenerative furnace, the chimney must be made of sufficient area to take off the damp air coming from the drying stove, and should have a small furnace at its base to aid in maintaining a proper

draught, especially as it is not advisable to build a very lofty chimney.

In his 'Études sur la Ventilation,' General Morin gives some formulæ which will be of service to anyone having to design foundry stoves, and who may wish to calculate somewhat closely the supply of heat, the volume of air, draught, height, and area of chimney required, and similar details.

CHAPTER XX.

FOUNDRY PITS.

The pits necessary for heavy work are either sand-pits or open pits. The former are filled with sand, to the level of the floor, which is dug to form a sufficient cavity, not only to enable the loam mould to be lowered into it, but also to allow the labourers to fill and ram the sand in again, firmly all round the loam mould, as a sufficient support to enable it to resist the pressure of the fluid metal inside it.

Sand-pits are used where the loam mould is built up, both in core and cope, upon a skeleton framework of common or loam bricks, or in such other manner as not to have sufficient stiffness in itself to resist the pressure of the liquid metal. The necessary support for the cope, or external portion of the mould, is here obtained by the filling in around it of the solidly rammed sand.

As to the cores, when these are circular in section, they are not found to require much support beyond the brick skeleton, but when they are irregular in shape, they are strengthened by stiffening pieces, or struts of wrought iron, or rings, applied according to the circumstances of the case.

Sand-pits are almost invariably used for the larger description of castings, and even where small work is the rule, a sand-pit is occasionally required. It should be about 4 feet larger in clear space all round than the largest mould which it is expected to accommodate, in order to allow ample room to dig out the sand and fill it in again around the mould.

The cylindrical form is that which is best adapted, both for economy and convenience, for a sand-pit; it should be surrounded with a brick wall, to prevent the sides from falling in, when the sand is removed. The depth and diameter of the pit depend upon the description of work it will be used for, but as a general

rule castings of large diameter are seldom very deep, and those which are of great height are seldom of large diameter.

Exceptional circumstances require special appliances to meet them, and it is scarcely worth while to constantly dig, wall, and fill in with sand, a very wide and deep pit, whose utmost capacity may perhaps only be tested once in twenty years. To partially overcome this difficulty, it has been proposed to excavate a central pit of considerable depth, surrounded by one of much larger diameter but of less depth.

Before filling in the pit, the sand should be screened, and wetted, and should then be thrown in, in successive layers, being well and equally rammed down all the time, by labourers in the pit. If this operation is carefully performed, the sand will well bear digging out from around the mould, and will stand up firmly like a wall. If, on the contrary, sufficient attention has not been devoted to this, the sand will come out unevenly, and will fall down in masses from the sides. In the case of large pits, this is a source of considerable danger to the workmen, and of loss to the employer.

If the mould and casting have not yet been removed, the fallen sand must be dug out; whilst should a fall occur just after the core of a large mould has been lowered into the pit, and before the cope has been properly adjusted in its place, it is most probable that the core will be damaged by the falling sand, or the least evil will be, that it will absorb some moisture from the damp sand.

In digging out or filling in deep pits, some precautions should always be taken to protect the men against the falling sand, by placing struts and poling boards against the sides, as is usual in all deep excavations, and is the more necessary with such material as sand. In digging out the sand from large pits, it is necessary to caution the men on the upper bank not to walk too close to the edge, so as to avoid bringing down the sand upon the men below.

When the pit exceeds 8 feet in depth, it is usual to excavate the sand by the ordinary staging process, having labourers on each stage, to throw the sand to the stage above, until it reaches the bank, where more labourers must be stationed to shovel it back from the edge of the pit, which must be cautiously done.

The sides must be supported with struts and stout poling boards, and sometimes rings of angle iron, in three or four seg-

ments, are lowered into the pit, and bolted together, thus forming a very strong circular support for the edges of the bank. Into the interval between the ring and the poling boards, hard wood wedges are firmly driven. One great advantage in the use of angle-iron rings to support the poling boards, is that cross struts are thereby avoided, and the rings and poling boards need not be removed until after the mould has been lowered into place, and it is necessary to ram in the sand around it.

One or two light ladders should be left in the pit, until it is so far filled in, that the men can leap out on to the bank in case of a sand fall.

The walls of dry pits are generally built of brick, sometimes of stone. The circular form is the strongest, most economical, and as a rule the most convenient, and the bottom should be laid with a slight fall towards the centre.

If the soil around and beneath the pit is wet or shifting, a good concrete foundation must be put in, and concrete must also be run in around the walls, which must be built strong enough to resist external pressure. In a watery soil, the whole mass of the casing must be of sufficient weight to counterbalance its displacement, so as to ensure its not being lifted, or floated, bodily upwards out of its site by water.

Such an accident is most unlikely to occur, except where a pit might be placed near a river, whose rising water could permeate the soil around the pit. But as a rule a water-logged soil is, and should be, avoided for the site of a foundry. These pits are occasionally lined with thin wrought or cast iron plates; when casting in such pits, however, precautions must be taken that the molten metal does not come in contact with iron casing, as it would probably crack or damage cast-iron plates, or stick in lumps on the wrought iron. In fact iron casings are better avoided, and are seldom really necessary.

Open pits are simply dry pits with flat bottoms, placed below the sand floor of the foundry, within the sweep of the cranes, and of such a depth as will allow the moulds to be stood within them, without rising much above the top edge of the pit.

Open pits are employed where the loam or dry sand mould is built up within a flask of cast or wrought iron, which casing is

sufficiently strong not only to support the mould, but also to take the thrust which comes upon the mould, when the metal is poured into it. The dimensions of the open pits are regulated by the size and form of the castings for which they are intended.

In most cases where any large castings have to be made in numbers of a similar size and shape, such as large pipes or columns, it is more economical to provide iron cases for the moulds, whether these are of dry sand or loam, and thus to be able to use the open pit when pouring. The moulds must be properly secured in position in the pit by struts and stays, unless of such a form as not easily to be displaced.

When it is necessary to withdraw a casting from the pit, the sand should be dug out all round down to the bottom of the mould, before attempting to lift the casting out by the crane. This is a point to which sufficient attention is frequently not given, as the moulders, in their haste to extract the work from the pit, sometimes leave in the last 3 or 5 feet of sand, loosen it slightly round the edges, affix the crane chain to the casting, and cry "Haul away!" If the sand has been well rammed in it will oppose considerable resistance to the pull, and the casting or the crane chain will probably be strained, whilst in the end no time is actually saved, as the sand in the pit must eventually be removed to be wetted and otherwise treated before being again rammed in. One great advantage of casting in deep sand-pits is the power it gives of casting bodies, such as large pipes and cylinders, in a vertical instead of in a horizontal position. It is well known that casting in this manner tends to improve the metal in the body of the work, and affords a ready means for extracting from the casting dross and air-bubbles, which rise into the open part or rising head of the mould.

To reap the full advantage of this tendency, the metal should not be poured directly into the top of the mould itself, as it would probably fall with too great a blow, and would in falling carry a large quantity of air with it. The plan which is found most successful is to convey the metal by vertical gates to the lower part of the mould, to pour the metal into these, so that it flows upward in the mould, when the air-bubbles and dross will float to the surface, and be then easily removed, whilst the body of the casting will derive all the advantages which accrue from the pouring

with a head of metal. Fig. 2, Plate XLIX., is an example of this plan.

The fact that casting under pressure consolidates and strengthens the iron is partly accounted for by its increased specific gravity, for taking two samples of the same make of pig iron, and casting them under different conditions, that which has the higher specific gravity will be found almost invariably to be the stronger. Yet, as there are so many other elements to be taken into consideration, it by no means follows that the specific gravities of two samples of a different make of iron can be taken as indicative of their relative strengths (sp. grav. C. I. ranges between 6·2 and 7·8). It is, however, indisputable that the more the specific gravity of cast iron is increased during the process of casting, other things being equal, the stronger it will become.

The readiest way of attaining this end is that of casting under a pressure, and various modes of doing this have been devised. Chilled castings have always an increased specific gravity, due to alterations in the molecular and chemical constitution of the metal.

Robert Mallet, F.R.S., made some most valuable experiments, to determine the rate of increase of specific gravity, obtained in the same irons, by casting under vertical heads of liquid metal, gradually increasing from zero up to a 14-foot head. A very interesting account embodying the results of these experiments was published in the transactions of the British Association of 1840, from which it appears that the three samples selected for experiment were of the following makes; *Apedale*, Derbyshire iron; *Calder*, Scotch iron; and *Blaenavon*, South Wales.

The castings made were all of the same size and shape; they were poured by gates in the bottom into dry-sand moulds, and all the circumstances as to temperature, rate of cooling, and the like, were preserved as nearly similar as possible. The density of the metals and the total increments of specific gravity were found to be as follows:—

	Spec. Grav. Head = 0.	Spec. Grav. Head = 14 Feet.	Differences.
Apedale	7·0328	7·1183	0·0137
Calder	6·9551	7·1035	0·0128
Blaenavon	7·0479	7·1430	0·0142

In the Apedale iron, the specific gravity increased with tolerable regularity at every 2 feet additional head; but with the Calder and Blaenavon irons, the chief portion of the increase was obtained with the first 4 and 6 feet of head, after which, although the densities continued to increase, the rate of increment was a gradually decreasing one.

Consequently it would appear, that with a still greater pressure than that due to 14 feet head of metal, the density of the cast iron would be further increased. Pressure has also been obtained by exhausting the air from the moulds at the time of pouring, thus obtaining a pressure of one atmosphere, which could also be increased by admitting compressed air in upon the top of the mould, so as to press upon the metal.

CHAPTER XXI.

CRANE LADLES.

A FOUNDRY must be well provided with ladles, varying in size from the smallest, which one man can easily carry, up to those capable of holding two, three, or five tons. Of the smallest size, which are similar in form to Fig. 3, Plate XIII., but generally made in one piece, a good many should always be kept in stock; of the larger sizes, the number must of course be determined by the class of work it is usual to contract for in the foundry.

Figs. 1 and 2, Plate LXXIII., are a plan and elevation of a common form of heavy ladle, generally made of boiler plate, which should be strong and thick, with double-riveted butt joints, heads of the rivets inside, and a strong angle-iron ring round the bottom.

The shape is cylindrical, with the bottom slightly concave inside, and it is usual to roughen the internal surface with a view of giving a better hold for the loam coating. The plates of the ladle are frequently perforated with a number of holes, about half an inch diameter, a precaution which is especially useful in large ladles, as allowing an egress for the gases, which are generated in the lining, when the molten iron is run into them from the cupola. The tendency of these gases, if pent up, is to split off some of the lining from the ladle; the liquid cast iron then coming in contact with the plates heats them to a dangerously high temperature, when the least evil to be anticipated is the bulging of the sides from their correct form, thus interfering with the action of the gearing employed for tilting them, when pouring into the mould.

The body is surrounded by a strong iron ring, from which two trunnions project; over these, the holes in the frame fit, the upper bar of the frame having a stout eye, for slipping on to the hook of the crane chain. A loose swinging fork is arranged on one of the upper edges of the ladle, and by throwing this into, or out of, gear

with the side of the frame next to it, the ladle is kept vertical, or swung over at pleasure. A handle fits on to the prolongation of one of the trunnions, and is a rough means of regulating the quantity and rate at which the metal is poured.

Before commencing to line the ladle, it is advisable that it should be slightly heated; the furnace man then gets inside it, and having coated the interior with a wash of clay of about the consistence of cream, he proceeds to apply the loam to the bottom of the ladle in a uniform coating from 1 inch to 1½ inch thick, using the utmost precaution to force it into close contact with the plates at all points. In working upwards the thickness of the lining is slightly reduced, and the covering of the lips must be neatly rounded off, so as not to oppose any uneven surface to the flow of the metal, whilst at the same time it must be prevented from coming in contact with the iron of the ladle. When the lining is completed, the ladle is allowed to stand, until the loam has dried sufficiently to allow of the ladle being turned upside down, without disturbing the lining. A fire is then lit beneath the ladle, so as to completely dry the lining. The ladle must be slightly tilted on one side, to allow the damp air and smoke to escape. The nature of the fire thus applied somewhat depends upon the convenience of the works, but one of the simplest and readiest modes is to place a pile of ignited coke on a piece of old sheet iron, and run it under the ladle.

If any cracks are observed in the lining during the process of drying, they must be filled up with moist loam, and when the whole is perfectly dry and uniformly covered, without cracks or flaws, a coating of thick blackwash is applied. When about to toss the metal into a ladle, an old piece of plate should be placed in a sloping position, resting against one side of the bottom, so as to prevent the first force of the current of metal from coming into contact with the lining; this plate must be removed with the tongs, when there is metal enough in the ladle to receive the flow of the falling metal. The "breaking of the iron" in the ladle is useful as an indication to the founder of its temperature.

The currents are more rapid, and the bright lines dividing up the surface are more irregular and transitory, when the metal is first run into the ladle than afterwards.

By a close observance of this curious phenomenon, the founder is enabled to judge the right moment for pouring, as it is seldom advisable to do so when the iron is at a much higher temperature than is necessary to ensure its penetration to every part of the mould, and making a clean sharp casting. Small ornamental work must be poured at a higher temperature than large heavy castings.

If the metal in the ladle is considered to be too hot to pour, a few pieces of perfectly dry, clean scrap iron are plunged into the ladle, where they will absorb some of the excess of heat, in the process of being melted. The iron thus put into the ladle has a strong tendency to float; it must therefore be forced down with the tongs, but the greatest care must be exercised not to damage the lining in so doing.

A convenient mode of tipping the ladles is obtained by the arrangement shown in Figs. 5 and 6, Plate LXXIII.

The strong wrought-iron cross-head is brought down on each side to nearly the bottom of the ladle, where it is bent round extra strong lugs or trunnions. Upon one of these trunnions is keyed a cast-iron worm wheel, which is geared into by an endless cast-iron screw, carried by bearings attached to the side bar. The end of the axis of this screw is square, so as to fit the socket of the long shaft, which is caused to rotate by means of a capstan wheel, fixed at such a distance from the ladle, that the man working it shall not be inconvenienced by the heat of the metal in the ladle.

This arrangement enables the ladle to be quickly, and safely, tilted to any desired angle. In order to ensure its steadiness when in an upright position, the usual forked catch with a hinge is riveted on one side of the ladle; the fork embraces the vertical arm of the cross-head, thus preventing any movement out of the perpendicular until the catch is disengaged.

For conveying the filled ladle from the cupola to the mould, an overhead traveller can be used, or a small but strong wrought-iron truck, running on light rails, may be employed, so arranged as to run the ladle within command of the sweep of the crane used in pouring. The rails should be laid a few inches below the usual floor level of the shop, and when not in use, be covered in with sand, to protect them from any liquid metal that may be spilt.

The wrought-iron carriage for the ladle is usually constructed

by mounting four small cast-iron flanged wheels on strong wrought-iron axles. Two cross-bars are riveted to the axles, a little farther apart than the diameter of the ladle; these are slightly cranked upwards, so as to embrace the ladle between them, which rests on the axles. Two strong hooks are fixed on each axle, to which the chain is attached by which the ladle is drawn along the rails.

Projecting horizontally a few inches from each side bar is a square stud, which is used as a means of arresting the motion of the truck; this is effected quickly, but without any jolt or jar, by a workman who follows the truck. He is provided with a long iron bar, which he slips under the stud, and rests upon the top of the rear wheel, when a slight downward pressure is sufficient to bring the ladle to rest.

By the use of well-laid rails, preferably without any inclines, and the above simple but effective brake apparatus, a large ladle, full to within a few inches of the top, may be conveyed from the cupola to the mould in a very short time, with very little power, so steadily as not to spill any of the contents, a very desirable result, on the score both of economy and of safety.

The chains for moving the trucks along the railway are sometimes drawn by manual labour, but a more steady motion is obtained by winding the chain upon a barrel at the end of the line of rails.

Having the ladle conveniently placed over the mould, the foreman in charge will direct the men to commence pouring. A skimmer should stand on each side of the ladle, if it be a large one, to remove all the slag and other impurities floating on the surface of the metal, and to prevent as much of them as possible from flowing into the mould. For this purpose they use a skimming tool, consisting of a flat blade of wrought iron fixed on to a long handle of round bar iron. To prevent the oxidation of the surface of the metal, powdered charcoal is plentifully thrown on it. But in any case a certain amount of dross will be found on the top of the ladle, and some of it will evade all the dexterity of the skimmers, and flow into the mould, to the great risk of spoiling the casting. This danger could be almost entirely avoided, if it were possible to use in general foundry work, a ladle similar in construction to that adopted in casting Bessemer steel ingots. The

steel from the Bessemer converter is poured into a large crane ladle, whence it is run into a number of cast-iron ingot moulds, arranged in a circle within the sweep of the hydraulic crane, which moves the ladle from immediately over one mould to the next, until its contents, except the impurities floating on the surface of the metal, are emptied. The ladle is discharged by removing a conical plug from a hole in the bottom, so that the metal flows with considerable force into the iron moulds. In this case the force due to the head of metal in the ladle is of no great importance, as it will not injure the cast-iron moulds, but in general casting work it would be very undesirable, as it would be almost certain to wash away portions of the mould.

CHAPTER XXII.

FOUNDRY CRANES.

The proper form of crane to be employed in a foundry is a question upon which there naturally exists considerable diversity of opinion, the system in use being varied to a considerable degree. Foundry cranes may be roughly divided into two classes, swing cranes, and overhead or travelling cranes, those divisions being subject to a good deal of amplification.

Figs. 1 and 2, Plate LVII., are views of a substantially built 15-ton crane with timber framing, arranged with compound braces, by Wm. B. Bement and Son, Philadelphia. The wheel or winding drum is driven by spur gearing worked by a winch. The traversing movement is attained by means of the gearing upon the beam, which, through a chain, indicated in the dotted lines, moves this gearing out or in upon the top beam.

When the load is suspended at the end of the crane, the vertical brace is subjected to a tensile strain, which is provided for by its attachment to the iron shoes at the end. To resist the torsional strain in the saddle, caused by the diagonal draught of the main chains, an arm is projected some distance from the saddle, and carries a roller, Fig. 1, that presses upon the inside of the framing, and relieves the main track. The sheaves and general tackle are of the ordinary construction.

Figs. 1 and 2, Plate LVIII., are an example of a fixed steam-crane for foundry purposes, the main framing of which is made wholly of wrought iron. The sides of the frame are stiffened at their edges by angle irons. The larger and more powerful cranes of this class are fitted with this construction, the smaller being made of sufficient stiffness without them. The crane represented in the Plate has two steam cylinders, with link-reversing motions, single and double purchase gearing; the barrel has a spiral groove for preventing the chain from overlapping or swinging. There is a

racking in-and-out motion to the jenny, return block and double-chain, and power-slewing gear. The smaller sizes of these cranes have only one cylinder, and are not made with the gear for slewing. Hand motions are fitted to each, so that in the case of the engines or boilers becoming out of order, no inconvenience may arise by the delay that would otherwise be caused.

The steam-pipe is, as a general rule, passed through the top pivot of the crane into the cylinders, but in exceptional cases through the bottom pivot; this latter mode should be avoided if there is any preference: in other examples, when the crane is not required to describe an arc of more than 180°, the steam-pipe may be brought to the centre line of the crane by a joint, without passing through the pivots. This latter plan has been applied to a good many cranes, when steam has been required to replace manual labour; the boiler may be fastened to a tank or platform at the side or behind the crane, and revolve with it.

Iron frame cranes to be worked by hand are usually similar in every respect to the steam-crane just described, and have a radius of from 12 to 20 feet, but the steam fittings are of course dispensed with, and handles fitted to the barrel.

Hydraulic cranes have of late years been introduced with great advantage where water under sufficient pressure is available. The form of hydraulic crane used at Sir Wm. Armstrong's works is represented in Plate LIX. The jib and pillar of the crane are of wrought iron, and revolve in top and bottom bearings. The crane has three motions, namely, lifting, turning, and traversing, all of which are effected by hydraulic power. The lifting cylinder A is made of double power, that is, it will lift slowly or quickly as desired by a ram and piston arrangement, which we need not describe, the highest power being equal to 20 tons; the ram is 11 inches in diameter, and the piston 15½ inches in diameter, the length of stroke being 6 feet 8 inches. The turning cylinders B are applied in the usual manner at the foot of the crane pillar, the rams being each 4½ inches diameter, with 5 feet stroke; and both the lifting and the turning cylinders, with their valves, are fixed in a chamber beneath the level of the floor. A three-port slide-valve is used for the two turning cylinders, and mitre valves for the lifting cylinder. The chain from the lifting cylinder is carried

upward through the crane pillar, bending over a sheave C at the top of the pillar, and passes successively over the pulleys of the travelling carriage D, and the running block E, and is finally made fast at the extremity of the jib. For the purpose of overhauling the ram of the lifting press, a small press is placed between the two turning presses B; and the overhauling action is effected by a chain being attached to the sliding head of the lifting ram at I. The pressure in the overhauling press is constant, and its action is therefore equivalent to that of a counterweight; the ram is 4½ inches diameter, with 3 feet 5 inches stroke. For effecting the traversing motion of the load suspended at the hook, the travelling carriage D is hauled inward and outward by two presses H fixed to the back of the crane pillar, and connected by chains with the travelling carriage; the ram of each press is 5½ inches diameter, with a 4 feet 7 inch stroke. The alternating action of these presses, which is precisely the same as that of the presses B used for the turning motion, is regulated by a three-port slide-valve K attached to the front of the pillar, with a lever at each side for working it. The water is supplied to and discharged from these presses by two pipes which pass through the top bearing of the pillar, and the connection between the valve and these pipes is effected in each case by a trunnion joint at J. J.

Fig. 3, Plate LVII., shows an example of Appleby's hand-power wall cranes. These cranes may be fixed on any wall, pier, or column of the foundry or forge; and so convenient are they that a traveller may be arranged over them if necessary. In foundries several of these cranes fixed diagonally with each other, are especially useful for the lighter branches of the work, as the floor in the centre, by this means, will be entirely free for the heavier duties of the overhead traveller, such as lifting heavy castings or ladles. The traveller is not then wanted for the lighter part of the work, as this is managed by the smaller cranes, perhaps more expeditiously than with the heavier ones. These cranes have been erected in several large foundries, and are proving in every way satisfactory.

Where work is at all heavy, it becomes a question as to the advisability of employing overhead travelling cranes, which have the great merit of leaving the moulding floor entirely clear. By means of such appliances we can also carry the flasks from the

outside of the building, and lower them at any given spot within the space traversed; while they can also be arranged to bring the ladles to the moulds, or remove castings to the fettling machines.

Overhead travellers are made of very various designs; the chief points to be observed in their construction being, the making of the main girders sufficiently strong for the weight they will be required to support; and in those worked by hand power the gearing should be of especially good construction, for it must be borne in mind that the gross weight of both traveller and load has to be moved every time the crane is put into operation. The girders are of several forms, some having timber beams and wrought-iron truss and tie-rods, while others are of wrought iron of various sections. The heavier varieties are fitted with a central or platform girder, which, to a great extent, supports the weight of the lifting and working gear with its framework.

Plate LX. shows a traveller with the main and platform girder composed of wrought iron, rolled in H section and trussed. This form of traveller is frequently used where lightness is required with a long span. The general arrangement of the crab gearing is as follows:—The lifting gear is single and double purchase, and the power is increased by blocks or chains, the upper sheaves for which are carried in the transome on the top of the side frames of the crab. The chain barrel is keyed into the large spur-wheel to relieve the shaft from torsion, the ratchet-wheel is cast to the flange of the barrel, and the brake ring is cast to the spur-wheel; the brake strap is lined with wood, and fitted with a hand lever. It will be seen that the two travelling motions are on one centre; the longitudinal motion, being the heaviest work, is given by the crank handle; the lighter work of the transverse motion is given by the hand-wheel, and as the attendant can have one hand on it and the other on the crank handle, a load can be simultaneously moved transversely and longitudinally any short distance required, a condition most favourable to some operations.

The advantages afforded by this arrangement of two crabs are, that when the maximum load is being lifted it is distributed between two sets of chains and gear, and over a great portion of the main beams; the men are not unduly crowded, and each man can apply his force with proper effect; the load can also be lifted

level, or be canted to any position required, or, for light work, one crab can be thrown out of gear and run to one end, and all the motions performed by the other. Travellers for loads of less than 20 tons are rarely made with two crabs, but this is entirely a matter dependent on the class of work the crane is employed to shift.

The travelling crane, Figs. 1 and 2, Plate LXI., is well adapted for a foundry where steam can without difficulty be applied for the purpose of driving a tumbler shaft, the length to be traversed longitudinally not exceeding 200 to 300 feet; beyond this distance, the torsion of the tumbler shaft becomes objectionable.

It was constructed to sustain a load of 50 tons for a span of 45 feet at the North-Eastern Marine Engineering Company's Works at Sunderland. It is one of the most powerful of the class to which it belongs, and was made by Appleby Bros. of London.

The main beams are wrought-iron fish-bellied box girders. The box section is also employed in the end cradles, which are fitted with six steel double-flanged wheels, fixed on immovable axles, the lubrication of which is performed from the centre. Such an immense weight is supported by each wheel, that it is necessary for them to be made of steel instead of iron; the four crab-wheels are also of steel. These latter could not be made with fixed axles, so are provided with movable double frames or journals. The crab is formed with single, double, and treble purchases, which are varied by means of a hand-wheel and screw. The barrel has a spiral groove, so as to enable it to take the chain without overlapping, the gearing at each end being so arranged as to provide against torsional strain on the barrel shaft. Three sheaves are provided to the top and bottom blocks, thus enabling it to give seven laps of chain. On the first motion shaft, besides the three different speeds of lifting gear, there is a set of geared change wheels and clutches; by these simple means the whole of the travelling and lifting speeds are completely changed, in the proportion of 2 to 1; thus, without disarranging the crane blocks, it gives the lifting speed of six powers, and two speeds of longitudinal and cross travelling, making the traveller, which would in other circumstances be slow and ungainly, into a very useful tool. Of course the greatest load of 50 tons would be an exception rather than an every-day occurrence.

The motions are transmitted by reversing friction clutches, which are copper-lined, the brake and pawl being connected and operated by a foot lever; when the brake is applied, the pawl is of course lifted out of gear. The motions of lifting and carrying can be simultaneously worked; the levers, being all brought together, enable them to be worked by one man at a point where he can see every movement on the part of his fellow-workmen, which is of very great moment, as he is compelled to labour almost entirely by signs of the hand, or some other movement, and any error, through a misunderstanding, might be the cause of considerable damage. Hand power is also supplied to the machine if required. In the trial of this overhead traveller with the maximum load of 51 tons, the deflection of the whole, including that of the longitudinal beam, was found on examination to be only three-eighths of an inch, and this was not permanent. The shaft can be easily lined up in case any settlement should be liable to take place in the foundations, the tumbler bearings being adjustable. The longitudinal shaft, from which all the movements are taken, is of 3-inch square iron, driven at the speed of 100 revolutions a minute.

The same shaft will, if necessary, drive several of these travellers.

In many large works, two somewhat elaborate systems of lifting have been employed, in which rope or cord is made the means of transmitting the power, instead of shafting. The first of these was introduced by Mr. John Ramsbottom, and the following description is from that gentleman's paper in the 'Transactions of the Institute of Mechanical Engineers.'

The cranes, upon Ramsbottom's system, are so constructed as to be driven by a light endless cord of small diameter, extending throughout the entire length of the shop traversed by the crane. This cord is driven at a very high speed, nearly 60 miles an hour; in consequence of which only a very slight driving power is required in the shifting gear of the crane. The driving cord is kept of uniform tension by the action of a constant weight, and is arranged so as to allow of the cranes working and traversing in every direction, without sensibly affecting the length of the cord.

The cranes of this construction in the Crewe Works are of two classes: longitudinal overhead cranes, lifting loads up to 25 tons,

and traversing-jib-cranes, lifting 4 tons. The cranes are all driven by endless cords running along the top of the shops, close to the roof tie-beams. The overhead traversers are worked in each case by a man seated on a platform attached to the crab, and moving with it; and the jib-cranes by a man standing below at the foot of the crane, and walking along with it when traversing; each man having control over the lifting, lowering, and traversing movements by a set of handles.

The construction of the cranes is shown in Plates LXII. to LXIX. Plates LXII. to LXVII. show the overhead traverser; and Plates LXVIII. and LXIX. the jib-crane.

Fig. 1, Plate LXII. is a transverse section of the engine-repairing shop at Crewe, and Fig. 2 is a plan, shortened in the direction of the length of the shop. The two pairs of overhead traversers A A and B B work on two parallel sets of rails, each having a span of 40 feet 7 inches, and a longitudinal traverse of 270 feet. The girders forming the longitudinal rails, are carried by the side walls and by columns, at a height of 16 feet above the floor. The two pairs of traversers are separately worked by the endless cords C C and D D, each cord being carried down the side of the shop, and returning along the same side, but at 4 feet lower level. The course of the cords is indicated by the arrows. In order to communicate motion to the traverser and crab, the driving portion of the cord is carried across each traverser to the farther end, and back again before passing on the main driving pulley.

The cord is returned round a tightening pulley E, 4 feet diameter, at the end of the shop, Fig. 1, Plate LXII., carried in a horizontal slide frame F, as shown to a larger scale in Figs. 1 and 2, Plate LXVII. To this frame is connected a weight G, Fig. 1, for the purpose of giving the requisite tension to the driving cord, and taking up any stretching or temporary variation of length due to change of load or weather. The tightening frame F has a traverse across the end wall of the shop, giving a range of 34 feet, which takes up a variation in the length of the cord equal to twice that amount. The traverser is shown in the side elevation and plan, Figs. 1 and 2, Plate LXIII., and Figs. 1 and 2, Plate LXIV., are transverse sections at the end and at the centre. It is constructed of two timber beams H H, trussed with wrought-iron bars; and the

whole is carried by four flanged wheels mounted in the cast-iron carriages, into which the ends of the beam H are fixed.

The longitudinal driving gear is placed at J, Figs. 1 and 2, Plate LXIII., at the end of the traverser, and is shown to a larger scale in Fig. 1, Plate LXVI. It consists of a double friction disc K, keyed on the vertical spindle of the driving pulley L, in which the driving cord runs. The spindle footstep and guide M are carried by the double lever N, which is connected to the short lever on the horizontal shaft O. This shaft extends across the whole length of the traverser, as shown at O O, in Figs. 1 and 3, Plate LXV., and is under the control of the attendant by means of the lever I sliding on the shaft along with the crab, whereby the friction disc K, Fig. 1, Plate LXVI., is raised or lowered, so as to be brought into contact with the friction pulley P, either at bottom or at top, according to the direction in which the traverser is required to move. The motion of the friction pulley P is reduced by the worm or worm-wheel and spur-gear to the pinion shaft Q, which is carried across the traverser from end to end by means of pinions, driving the carrying wheel at each end of the traverser, Fig. 2, Plate LXIV. The frictional surfaces of the driving disc K are composed of rings of alder wood cut with the fibre on end; the edges of the wood rings are bevelled, and they are secured in their places by an inner iron ring, as shown black in Fig. 1, Plate LXVI.

The pulleys for returning the driving cord from the farther end of the traverser are shown separately in Fig. 3, Plate LXVII. They work in the inclined position shown, in order that the cord which has passed over the traverser may be returned at 1½ inch lower level, and at the same time in a different vertical plane, as shown at A. This is done in order to facilitate the lowering and lifting movements, as afterwards described, and further, in order that the two cords which are travelling in opposite directions, may not rub against each other by the swagging of either of them. These pulleys are keyed upon wrought-iron spindles, running in long bearings, which are placed wholly below the pulleys, on account of the small amount of clearance between the roof-principals and the pulleys, only 2½ inches. The weight of the pulley and spindle is taken by a brass footstep. The bearings are of cast iron, and are

chambered at the top for the convenience of oiling, which is done by raising the pulley by hand until the spout of an ordinary oil-can will reach the chamber. In the event of the cord leaving the pulley from any cause, guards are provided, as shown at A, in order to prevent accident.

The crab of the traverser is shown in Fig. 3, Plate LXIV., and Figs. 1, 2, and 3, Plate LXV., which gives a transverse section, a longitudinal section, and a plan. It consists of a pair of cast-iron frames, carrying a chain barrel, lifting and lowering, and traversing gear; the whole being carried upon four flanged wheels running on rails bolted upon the traverser beams H H.

The lifting and lowering gear is partly shown in detail, to a larger scale, in Fig. 2, Plate LXVI. The double-grooved pulley R is keyed to the vertical spindle, and is put in motion when the cord is pressed into either of its grooves by the presser pulleys S and T. These pulleys are of cast iron, 8 inches working diameter, and are mounted on short iron studs, tapped into the radial arm Z, on which they are carried, as shown in Figs. 3 and 4, Plate LXVI., and in the plans, Figs. 2 and 3, Plate LXV. The heads of the studs are recessed to form a receptacle for oil, Figs. 3 and 4, Plate LXVI., the oiling being done from the top, through a hole drilled in the stud for that purpose. When at rest the pulleys are clear of the cord, and are therefore only running when work is being done. The stud bearings are necessarily short, in consequence of the small amount of clearance between the pulleys and the roof tie-beams, which at this point do not exceed 1½ inch, as seen in Fig. 3, Plate LXIV., and Fig. 1, Plate LXV. The grooves in the driving pulley R, Fig. 2, Plate LXVI., are of different diameters, whereby different velocities are obtained, the smaller being used for lowering and the larger for lifting; and as the two portions of the driving cord are running constantly in opposite directions, the reversing is obtained by simply pressing one or other of the cords into contact with the driving pulley, by the presser pulley S or T, on the same side of the driving pulley in both cases, with a pressure proportionate to the work to be done. The radial arm Z carrying the pressure pulleys S and T, turns upon the spindle A, Fig. 2, Plate LXVI., and the toothed segment B, which is part of the same casting as the arm Z, gears into a

rack at the end of the rod C, Fig. 2, Plate LXV., attached to the hand lever D. The lever D is under the control of the attendant, and is held in its place by a spring catch in a notched sector.

From the driving pulley R, Fig. 3, Plate LXIV., and Fig. 3, Plate LXV., the velocity of the driving cord is transmitted and reduced through the worm and worm-wheel U, Fig. 3, Plate LXV. In order to economize space, the shaft of the worm-wheel U is carried through the hollow shaft on which the chain barrel V and its spur-wheels are mounted. The number of revolutions is further reduced by a spur-pinion and wheel to the shaft W, on which slide the two pinions X X, of different diameters, gearing alternately into the spur-wheels Y Y, also of different diameters, which are keyed to the chain barrel V, so as to give a greater or less purchase as required for heavy or light loads, the ratio of difference being about 4 to 1.

The cross-traversing gear E, Fig. 3, Plate LXV., is similar in principle to the lifting gear. The two grooves of the driving pulley F are, however, of the same diameter in this case, the velocity of traverse being the same in both directions. The pulley F is placed on the opposite side of the driving cord to the pulley R of the lifting gear, so that the cord, when used for traversing, may not foul the lifting pulley. The radial arm G, carrying the presser pulleys belonging to the driving pulley F, is worked by a rack and segment from the hand lever J, Fig. 2, Plate LXV., which is adjacent to the hand lever D of the lifting and lowering motion.

The cross and longitudinal traversing movements are made at the rate of 30 feet per minute. The heavy loads are lifted at the rate of 1 foot 7½ inches per minute, and the light ones at the rate of 6 feet 5 inches per minute.

Fig. 1, Plate LXVIII., is a transverse section of the wheel shop, containing the pair of traversing jib-cranes; and Fig. 2 is a plan shortened in the direction of the length of the shop. Figs. 1 and 2, Plate LXX., are a vertical section and front elevation of one of the cranes. Each of the two jib-cranes A A has a radius of 8½ feet, and a traverse of 120 feet along a single rail bolted to the floor; and is guided at the top by a pair of girders B B. Fig. 2, Plate LXX., of an ⊢⊣ section. The top of the crane carries the guide roller C, which just fits in between the two girders B, and serves to

support the crane laterally when lifting on either side of the rail. The driving cord is carried down to the shop and back again, as indicated by the arrows in the plan, Fig. 2, Plate LXVIII., just below the roof tie-beams. In its course, it is passed round nearly half the circumference of the driving pulley D of each crane, by means of the two guide pulleys E E, the one crane being driven by the outgoing cord, and the other by the return cord. The guide pulleys E are carried by a guide bracket upon the top of the crane post, Fig. 1, Plate LXIX., and traverse with the crane. The tightening gear F is similar in its action to that already described for the overhead traverser.

The crane is constructed of the plate-box frame G, Figs. 1 and 2, Plate LXIX., forming the base, and carrying the vertical cast-iron pillar H, round which the outer casing and its attached jib K revolve. The driving pulley D is keyed to the vertical shaft I, passing down the centre of the crane post, and from this shaft all the motions are taken by means of frictional gear. The lifting and lowering gear J consists of the double friction-cone of cast iron L L, sliding on a fast key on the vertical shaft I, and moved up or down as required, to bring the lower or upper frictional surfaces into contact with the single central friction-cone, from which the motion is transmitted and reduced through the worm-wheel and train of spur-gear to the chain barrel, as shown at J, in Fig. 1, Plate LXIX. The whole is carried by the cast-iron bracket N, which is bolted to the outer casing of the crane pillar, and revolves with it. The bearings for the driving shaft I above and below the double friction-cone L are of cast iron; but the horizontal worm-spindle runs in a brass bush, the end pressure, when lifting, being taken by the collar of the bush and the end step. The driving cones are raised or lowered by means of the double lever O O and brass clutches, as shown in the plan, Fig. 3, Plate LXIX., on each side of the boss of the lower cone L. These levers are placed under the cones instead of between them, in order that any oil thrown off the collars may not effect the frictional surface. The clutch levers are connected by an external rod to the hand lever P, Fig. 1, Plate LXIX., at a convenient height for the man working the crane.

The traversing motion shown at Q is similar in principle to the

lifting gear, consisting of a single friction-cone keyed on the bottom of the vertical driving shaft I, which communicates a backward and forward traverse when either face of the double cone S is brought into driving contact as required; the motion being transmitted to the carrying wheels by the horizontal shaft T, through the train of worm and spur gear indicated in Fig. 1, Plate LXIX. The traversing gear is applied to both the carrying wheels, in order that there may be sufficient adhesion when the load overhangs either end of the crane, which would not be the case if only one wheel were driven, and the load overhung the opposite end of the crane. The double cone S is moved along the horizontal shaft T by clutch levers U, in a similar manner to the lifting and lowering gear. The double cones S are of cast iron, but the driving cone is composed of a cone of alder wood, which is fastened by lock-nuts and studs to a wrought-iron disc screwed on the coned end of the vertical shaft. The traversing gear is carried by the bracket W, which is bolted to the foot of the centre pillar H, Fig. 2, Plate LXIX. The bearings of the horizontal shaft T are of cast iron, and the bearing of the foot of the driving shaft I is of brass, the weight of the shaft being taken by the collar of the bush, on which rests the lock-nuts screwed on the shaft at that point, forming an adjustable collar for taking up the wear and keeping up the driving pulley D, at the right level for the driving cord. The horizontal shaft T is carried at the end by cast-iron brackets, with brass bushes to take the end thrust in traversing; the worms are pinned on the shaft.

The jib K of the crane, Plate LXIX., is formed of two wrought-iron bars, stiffened laterally by diagonal trussing, and tied at the projecting end to the outer pillar of the crane by two tie-rods. The bottom pressure of the jib is taken by the roller X, which is carried in a cast-iron box, bolted between the projecting sides of the outer casing of the crane, and runs up the bevelled base of the cast-iron crane pillar H. The base G of the crane is sufficiently long to secure its stability when the maximum load is lifted over the rail, or lengthways of the crane base.

In these cranes, owing to the high speed at which the driving cord runs, the power is applied at a very long leverage over the load to be lifted. The velocity of the cord is in all cases 5000 feet per minute, and in the overhead traversers the heavy loads are

lifted at the rate of 1 foot 7½ inches per minute, the total leverage being slightly over 3000 to 1; so that in this case the driving power required to lift the maximum load of 25 tons is only 18 lbs., irrespective of friction. When lifting light loads with the traversers the speed of lifting is increased to 6 feet 5 inches per minute, being a leverage of nearly 800 to 1; and in the jib-cranes which lift up to 4 tons, the speed of lifting is 5 feet 1½ inch per minute, giving a leverage of nearly 1000 to 1. The actual power required in the traversers for lifting a load of 9 tons, besides the snatch-block and chain, has been found to be 17 lbs., acting at the circumference of the driving pulley at the point where the driving cord acts upon it; and the total leverage over the load being 3000 to 1, the portion required to sustain the load is 6 lbs., leaving 11 lbs. as the working power required to overcome the friction of the crab-gear under that load. The crab when unloaded is found to require a driving power of 1⅛ lb. to overcome its friction.

The tightening weight G, Figs. 1 and 2, Plate LXII., is 218 lbs. or 109 lbs. on each half of the driving cord; and this is found to be about the best working strain for keeping the rope steady, and giving the required hold on the main driving pulley, and the horizontal pulleys of the crab. The limit of the weight G, is that required to give steadiness to the transverse portion of the cord situated between the crab pulleys and the end of the traverser, which is unsupported for a length of about 30 feet when the crab is close to one end of the traverser.

The driving cords employed are soft white cotton cords, ⅝ inch diameter when new, and weighing about 1½ oz. per foot; they soon become reduced to about 9/16 inch by stretching, and are found to last about eight months in constant work. A smaller cord of about ⅜ inch diameter was originally used; it was, however, found desirable to adopt a cord ½ inch diameter afterwards. The total length of each of the two driving cords is, in Plate LXII., 800 feet, and in Plate LXVIII., 320 feet. The wear and tear of the cord is considered mainly to be influenced by the bends to which it is subjected in its course; and the pulleys over which it is bent are therefore none of them made less than 18 inches diameter, or about 30 times the diameter of the cord, excepting only the presser pulleys of 8 inches diameter, for pressing the cord into the grooves of the driving

pulleys in the overhead traversers. In the jib-cranes the cord has eleven bends at all times, whether the two cranes are working or not; and in the traversers the cord has twelve bends when both cranes are not working, sixteen when both are lifting or cross-traversing alone, and twenty when both cranes are traversing and also lifting.

The groove of the driving pulleys is made V-shaped at an angle of 30 degrees, and smaller at the bottom than the cord, as shown in the half full-size section, Fig. 7, Plate LXVII., so that the cord is gripped between the inclined sides and does not reach the bottom of the groove. In the guiding pulleys the grove is made half round at the bottom, with the same radius as the section of the cord, as shown in Fig. 8, and in the presser pulleys the bottom of the groove is rounded out with rather a longer radius, as in Fig. 9.

The cord is supported at intervals of 12 to 14 feet by fixed slippers of a plain trough section, in which it lies whilst running, as in Figs. 4 and 5, Plate LXVII. They are of cast iron, flat in the bottom, which is 1⅜ inch wide, and with side flanges as shown in the half full-size section, Fig. 6, Plate LXVII.; the ends are bell-mouthed, as shown in Fig. 5. These slippers are fixed 1½ inch below the working level of the cord on the driving side, Figs. 4 and 5, Plate LXVII., so that the driving wheels pass clear above the slippers in the traversing of the crane, and lift a portion out of them successively in passing.

In experiments made with a number of slippers carrying different weights, the friction between the cord and the slipper was found to be about ⅖ of the load; but as the total weight of that portion of the cord which rests on slippers is only 50 lbs., and the whole friction consequently amounts to only 20 lbs., it is not considered worth while to complicate the system by the introduction of pulleys for supporting the cord. No care in oiling is required as regards these bearing slippers used in transmitting the power along the shop, as is in the power cranes, driven by continuous longitudinal shafting, where tumbling carriers are required, or where heavy cords at low velocities are used, requiring carrying pulleys, the bearings of which need regular oiling. By means of pull cords passing from end to end of the shop, the main driving gear for each pair of traversers may be stopped at any time by the men

working the traversers, so that when the cranes are not working, the whole of the high-speed gearing stands idle.

The diameter of the worm-wheel U of the lifting gear in the 25-ton traversers, Fig. 2, Plate LXVI., is 24¼ inches at the pitch line, and this is driven by a worm 3 inches diameter at the pitch circle with 1 inch pitch, the inclination of the threads of the worm to the axis of the worm-wheel being 1 in 9½, 1 in 9·4. This is found to be safely within the angle of friction, so that the worm will not slip back with any weight it has to lift; and it thus affords a complete means of holding up the weight at any point, without the use of a brake, and of lifting or lowering it instantly without the slightest jerk. The pitch of the worms has, however, been so arranged that in lowering but little power is required further than to put the gearing in motion. The speed of the worms at the pitch lines is 833 feet per minute for the lifting gear of the 25-ton traverser, and 486 feet per minute in the jib-cranes. The pressure on the teeth of the worm-wheel in the traverser, when lifting the maximum weight of 25 tons, is 9¼ cwt., and in the jib-cranes when lifting the load of 4 tons, it is 7½ cwt. In the practical working of the 25-ton traversers, however, the strain seldom exceeds one-half of the given amount, since in lifting very heavy loads the two crabs are usually employed in conjunction.

The action of these cranes is very smooth and easy, and all the movements are readily under control, but they absorb a good deal of power. It is therefore essential to the successful working of this system to reduce the friction as much as can be by employing well-made carefully balanced pulleys, and having as few bends as possible. The pulleys at Crewe are finished by balancing them on a pair of parallel straight edges, and adjusting their weight by filing and scraping, until they remain at rest in any position; when so adjusted they work smoothly and steadily.

A system probably better adapted for heavy foundry practice, is that in which a steel-wire rope working with a clip drum is employed, instead of a cotton rope acting by friction only. A crane on this plan was described and illustrated by Mr. John Fernie in the Trans. Inst. M. E.' in 1868, from which we extract the following description.

The wire-rope crane, Plates LXXI.–LXXIII., is employed at the

Steam Plough Works, Leeds, for lifting heavy work ranging from 15 tons downwards; it has a span of 40 feet, and traverses a length of 180 feet. The three different motions for longitudinal traverse, cross-traverse, and hoisting, are all derived from one endless steel-wire rope, $\frac{3}{4}$ inch diameter, and weighing 2 lbs. per yard. This rope is driven at a speed of four miles an hour, by means of a clip pulley fixed at one end of the shop, which is driven by belts and gearing from the engine working in the shop. The rope extends the whole length of one side of the shop, going and returning on the same side at the level of the traveller, and passing round a loose pulley at the farther end. The rope is entirely unsupported between the two ends, and is not strained tight, but hangs loose with only a slight tension, because the peculiar action of the clip pulley allows of the whole power being communicated to the rope, by the grip of the pulley through half its circumference, even when the tail-rope is entirely slack.

The clip pulley A, Fig. 1, Plate LXX., fixed at the end of the shop, is speeded to drive the wire rope B B at the rate of four miles an hour, and lays hold of the rope with an amount of grip proportionate to the strain thrown upon the rope by the load, releasing it from its grasp when the rope has passed the centre line. The construction and fixing of the movable jaws or clips round the circumference of the clip pulley is shown $\frac{1}{8}$ full size in Figs. 3 and 4, Plate LXX. At one end of the travelling platform C of the crane, is fixed another clip pulley D, Figs. 1 and 2, Plate LXXI., of the same size and construction, round which the same wire rope passes, making three-quarters of a turn. The rope then passes on to the farther end of the shop, and round the groove pulley E at that end, Fig. 1, Plate LXX. This pulley is centred in a sliding frame provided with an adjusting screw G, for tightening up the rope to any tension required. It has not been found necessary to have any sliding weight attached to this frame, for variable tension of the rope. The wire rope has no slippers or carrying pulleys to support it, and is consequently free from the friction that accompanies their use, nor is it considered necessary to use carrying pulleys for distances under 600 feet. The shop for which the crane illustrated was made is 180 feet long, and the rope hangs in a catenary curve through that distance, the deflection from a straight

line being 3 inches to 2 feet, according to the degree of tightening by the end pulley E.

The gearing for working the longitudinal traverse and cross-traverse, shown to a scale of $\frac{1}{32}$, Plate LXXI., is of the ordinary description, the motion being communicated from the clip pulley D on the traveller, by means of friction clutches. The longitudinal traverse has a speed of 30 feet per minute, and the cross-traverse 20 feet per minute.

The lifting gear consists of a very long cast-iron nut, or screwed barrel H H, extending nearly the whole length of the traveller, as shown in the plan Fig. 2, Plate LXX., and to a larger scale in Figs. 3 and 4, Plate LXXII.; and inside the barrel works a short screw I, Fig. 3, Plate LXXII., sliding on two feathers upon the long shaft J J, which is driven by a friction clutch from the clip pulley D on the traveller, so that by the revolution of the shaft, the screw is traversed along with the barrel. The long driving shaft J is supported at intermediate points of its length, by the two sliding brass steps K K, Figs. 3 and 5, Plate LXXII., sliding along freely with the barrel H, and kept apart from each other at the distance of half the length of the barrel by the rod L; by this means the shaft J is never left unsupported for more than half its length. The screwed barrel H is cast in two halves longitudinally, and bolted together, as shown in Fig. 4, Plate LXXII., and the pitch of the screw head is $1\frac{3}{4}$ inch, the diameter being $6\frac{1}{2}$ inches. One end of the hoisting chain being attached to the screw frame M, Fig. 3, the chain N passes along through the inside of the barrel H, round a pulley P, at the farther end of the traveller; then over a pulley on the cross-traversing carriage R, Figs. 1 and 2, Plate LXXII., down to the snatch-hook S, and up again over a second pulley on the carriage R; and the end is attached to the nearest extremity of the traveller at T. There is no reason, however, why an ordinary crab might not be used, worked by a shaft extending from end to end of the traveller; and that plan is adopted in some instances; but for heavy weights it is still considered that the long screwed barrel above described is preferable. The crane has two speeds for the lifting gear; one being at the rate of 6 feet per minute, the other at the rate of 3 feet per minute, and at the latter speed the crane is calculated to lift 15 tons.

It is most desirable that all machinery of this kind should be kept running constantly, so as to be available for immediate use at any moment when required, without any delay for starting it to work; but inasmuch as the total time during which the crane is actually in use does not amount to more than about one hour out of ten, it is of special importance that the power employed to drive the rope when the crane is not in use should be reduced to as small an amount as possible. If a quick running rope is employed, the absorption of power for keeping it in motion forms a large proportion of the total power required when lifting a load, and this is a loss which is going on throughout the day; but when a low speed of rope is employed, the constant loss is greatly reduced. The pull required to put the rope in motion when the crane is standing idle is 128 lbs. When lifting a load of 10 tons at the usual speed of 3 feet per minute, the additional pull upon the rope due to the load is 191 lbs., making a total pull of 319 lbs. and the horse-power required with the wire rope is consequently 3·4 horse-power with a load of 10 tons, and only 1·4 horse-power when standing idle, these amounts being very much less than in the case of the quick-moving cord crane.

CHAPTER XXIII.

CAST STEEL.

The detailed consideration of the various processes employed in the manufacture of steel would be a digression from our subject, and the present chapter, therefore, deals only with that mode in which casting steel from the crucible is employed. In treating the subject of steel at large, Mr. W. E. Hackney, in a recent paper read before the Institution of Civil Engineers, gave a remarkably clear account of the manufacture of crucible cast steel; to this paper we are largely indebted for our information.

The fusion of the materials in crucibles is the simplest and oldest form of making steel, and has been practised by the Hindoos from a very remote period. In the Hindoo process, a small quantity of wrought iron, from ½ lb. to 2 lbs., either in one lump or cut into pieces, is put into a crucible of unbaked clay, together with one-tenth of its weight of dried mould, the whole being covered with one or two green leaves and luted over. From fourteen to twenty-four of these small crucibles are stacked together, when the luting is dry, in the form of a dome or beehive, an opening being arranged by withdrawing one crucible from the lowest row, to form a firing hole. Fire is lighted inside the dome of crucibles, and the inside space is filled with charcoal, which is also heaped over the top. The fire is urged by bellows, the blast being introduced into the fireplace by a clay pipe, and in from two and a half to four hours the operation is completed. A new arch of crucibles is then constructed, and the process goes on night and day.

The resulting steel, termed "wootz," is obtained, on breaking open the crucibles, in the form of melted cakes, moulded to the shape of the pots. These cakes are reheated for several hours to a temperature just below their fusing point; they are then allowed to cool down, and are drawn out at a very low red heat, as the metal cracks or crumbles to pieces under the hammer if an attempt is

made to forge it at a higher temperature. A forged bar of wootz, analyzed by Mr. Henry, contained—

Combined carbon	1·333	per cent.
Uncombined carbon	0·312	„
Total	1·645	„

or nearly the maximum quantity that is found in any metal that can be classed as steel. The object of making wootz with so high a percentage of carbon appears to be to render it more fusible, so that it may melt at the very moderate temperature that can be maintained in the rude little furnace just described; the fusibility of compounds of iron and carbon increasing regularly as the percentage of carbon becomes greater. Indeed, as Heath has suggested, it is probably found necessary, in order to ensure the fusion of the metal, to employ a larger dose of carbon than suffices to form the hardest steel, and the excess is subsequently removed before hammering by the prolonged exposure of the cakes of metal to the flame.

It does not appear that any mode of producing a true steel, that is a melted forgeable variety or alloy of iron, was known in Europe before the last century.

Réaumur, in 1722, published the fact that he had been very successful in making steel by melting together from a quarter to a third of malleable iron, with cast iron in a common forge. Such a mixture would produce a highly carburetted and comparatively fusible metal, much like wootz; and, indeed, it is only within the present century, that the improvements in crucibles and in furnaces have rendered it possible to manufacture a really mild steel. No practical use seems to have been made of Réaumur's observation; but Huntsman, a clockmaker, of Doncaster, commenced, between 1750–70, what appeared to have been a totally independent series of experiments, which resulted in the successful production of cast steel. Huntsman's object was, it is said, to obtain a more reliable material for clock springs than the shear steel, or highly carburetted "converted" malleable iron then used. The process he employed was that of simple fusion of converted bar iron of the required degree of hardness, a process that still holds its place for the production of the highest qualities of tool steel.

From the time of Huntsman the principal improvements in the crucible processes of steel making have been that a small proportion of manganese, in one form or another, is generally added to the metal, the effect of which will be considered farther on; that the size of the pots has been increased; that two, and sometimes four, are heated in each furnace, instead of only one, and in many works the regenerative gas furnace is now in use for melting, in place of the pot-hole fired with coke; that very much milder, less fusible metal is now often melted; and that, as the knowledge of the chemistry of the subject has advanced, every possible mode of making steel in crucibles has, at one time or another, been either tried as an experiment or worked on a commercial scale.

Thus the direct melting of converted malleable iron of the required degree of hardness, was the process of Huntsman, and is that still used at Sheffield for making best tool steel; and, according to Percy, highly carburetted puddled iron, or "puddled steel," has also been used largely as a material for direct smelting by Krupp, as well as by several Sheffield firms.

The plan of melting soft malleable iron with carbon is the old Hindoo process; a modification of it, the production of steel of different degrees of hardness by varying the proportion of carbon, was patented by David Mushet in 1800; and, in modern practice, if the metal charged into the pot is a little too low in carbon to make steel of the temper required, nothing is more common than to add a small quantity of charcoal.

The fusion of reduced spongy iron with charcoal or other carburetting agents is the well-known Chenot process, a system of manufacture from which much was expected when it was first brought forward, between fifteen and twenty years ago, but which does not appear to have proved a commercial success; though, from a note in the 'Journal of the Iron and Steel Institute for 1872,' it would seem that so recently as 1871, it was still in use both at Clichy, near Paris, and in Spain. The cost of labour in the Chenot process is high; the consumption of fuel in reducing the ore to metallic sponge is considerable; the reduction is never uniform and complete; and the final operation of fusion in crucibles is expensive, as the sponge, though strongly compressed into little cylindrical blocks before it is charged into the pots, is, weight for weight,

more bulky than cut-up pieces of compact iron; so that the weight of metal got out of each pot is much less than in melting solid iron, while the cost of fuel, and nearly all working expenses, are equally great.

The fusion of malleable iron with cast iron is the old process described by Reaumur more than 150 years ago; since then it has been frequently employed, and at the present time it is of all the pot-steel processes perhaps the most largely used, especially in making the milder qualities of steel, for tires, axles, springs, or wire. Puddled iron of good quality, or mild Bessemer steel scrap, is the material generally melted; and manganiferous pig iron, or spiegeleisen, is the variety of cast iron preferred, as this adds at once carbon and manganese.

Hard malleable iron, or scrap steel, too highly carburetted to produce by itself the variety of steel to be made, is frequently melted with the admixture of a small proportion of oxide of iron or of manganese, in order to remove part of the carbon from the metal, and also, in the case of oxide of manganese, to put manganese into it; or if manganese is to be put in, without altering the hardness of the metal, oxide of manganese is added, with a sufficient proportion of spiegeleisen or of charcoal to reduce it to metal, without abstracting carbon from the steel.

The fusion together in crucibles of granulated cast iron and iron oxide or iron ore is the well-known Uchatius process, which, according to Percy, was, in 1862, in successful practice in Sweden.

The plan of making steel by melting down together ore and carbon at one operation, was patented by Lucas in 1791, by David Mushet in 1800, and again by Hawkins in 1836, and it has often, by way of experiment, been tried since. Very good steel for chisels and other tools may occasionally be made in this way, but the hardness of the metal is uncertain, and the plan has, even to a greater extent than that of Chenot, the disadvantage that the material is very bulky compared with the weight of steel it yields; so that only a small quantity of metal can be got out of each pot.

Examples of the furnaces now used for melting steel in crucibles are shown in Plate LXXVI. Figs. 1 and 2 represent the ordinary pot-holes at Vicker's works in Sheffield, in which coke is the fuel used. Each hole or furnace is a simple rectangular chamber,

communicating near the top with a large main flue, which is common to a row of furnaces. The tops of the furnaces are on a level with the floor of the melting shop, and the grates are accessible from the cave below. Each furnace is covered by a square fire-tile, or quarry, fixed in a wrought-iron frame, from which a handle projects in front. The furnaces are lined with ground ganister, a variety of millstone grit that is found near Sheffield, and is of great value as a fire-resisting material. When the furnace is to be relined, a wooden mould is put into it, and the ground material rammed round.

The pots almost invariably used are of fire-clay, mixed with a little coke-dust, and sometimes also with a little burnt clay, old ground pots, to make the mass more porous, and thus diminish the risk of cracking. The mode of making and annealing the pots is described in the chapter on crucibles, page 115. The pots vary much in size: thus, some hold a charge of only 28 lbs., and others from 40 lbs. to 45 lbs. The present tendency is towards the use of large pots, holding 55 lbs. to 70 lbs. for the first charge, and 5 lbs. to 10 lbs. less each time they are refilled, in order that the flux-line, the level of the surface of the liquid steel, where the chief corrosion of the pot takes place, may not come twice at the same height. When pots of plumbago or black-lead ware are used, they are frequently made to hold 75 lbs. Clay pots stand from two to four rounds, depending on the fusibility of the steel melted, and black-lead pots about twice as many. Black-lead pots are, however, seldom used, except in melting the very mildest qualities of steel, such as the boiler-plate metal, for which Pittsburgh has acquired a deserved celebrity; steel so refractory that the best clay pots will soften and burst at a heat little greater than that required to render the steel liquid.

Three charges or rounds are melted in twelve hours, and generally the melting is carried on by day only, as the wear of the furnaces is much increased by working them day and night. The consumption of coke is from 2¾ to 3½ tons per ton of steel melted, equivalent to from 4 to 5 tons of coal.

The preparations for melting the steel are commenced by making a coal fire upon the grate adjoining the annealing grate. The annealing grate must be large enough to hold twice as many pots

as there are melting holes in the furnace. If that number be ten, twenty pots are put inverted upon the annealing grate, and the fire put down the spaces between them, which are then to be filled up, so as to cover the pot with the small coke riddled from among the coke used for melting, and upon these again the pot-lids are laid. This is done in order to have the pots gently heated to a red heat, ready for using. Each pot requires a stand and a lid. In form, the stand is the frustum of a cone about 3 inches high; and as upon the base of the stand the pot is to rest, they should correspond in size. The stand is made of common fire-clay, but the lid of clay the same as the pot; it should be a little larger in diameter, flat on the under side, and a little convex on the upper. Each furnace has two stands placed in the proper position upon the grate-bars; and upon the stands two pots, covered with their lids, from the annealing grate. Some fire, with a little coal, and soon after some coke, is put on; and when this has burnt up, sufficient coke to cover the pots; when the furnace and pots are at a white heat, the steel may be put in. The steel, having been broken and selected for the intended purpose, weighing say 34 lbs. for each pot, is put into pans of iron or upon steel plates. To charge a pot, the lid is taken off, and the lower end of a conical-shaped charger placed over the pot, down which the steel is gently slid. The lid is then replaced, and the other pot being charged in the same manner, the furnace is filled with coke, and covered. Afterwards more coke is added, the quantity being determined by the experience of the steel maker.

Four hours will finish the heat, when a man removes the crucible, by means of basket-tongs, from the fire, and puts it on the floor. Another workman takes the pot and pours the metal into the mould. Meanwhile the furnace is cleared of clinkers and made ready to receive the hot pot when emptied into the mould.

The Siemens furnace is also largely used in the production of cast steel; the following description of the cast-steel works at Eibiswald, in Sweden, will serve to illustrate the mode of working:—

"At these works the production of crucible cast steel is carried on in regenerative gas furnaces on Siemens' principle. The fuels used are brown coal and peat, the consumption being at the rate of

$2\frac{1}{2}$ cwt. per cwt. of steel melted in the newer furnaces, or 3 cwt. of those of the older construction. The former, 6 feet long and 3 feet broad, are adapted for twelve or fourteen melting pots, while the latter have a capacity of only nine. The gas generators are of the usual plan of those adopted in Styria, with steep grates and a plain grate at the bottom, and are worked with a blast under the grate. The regenerators, placed at right angles to the axis of the furnace, are of large capacity.

"The materials used for steel making are forge or cement steel ore and scrap, wrought iron and steel, which are charged into the crucibles, and brought to a full red heat in a tempering furnace, before being introduced into the melting furnace proper. The actual time required for fusion is about four hours.

"The furnaces are lined with quartz bricks set with quicklime, and the fire-bridges with bricks made of a mixture of five parts of magnesite from Leoben and one of quicklime burnt in round kilns with peat or brown coal.

"Crucibles of local manufacture made of five parts graphite and one of fire-clay are used, as, although they stand only one, or at most two meltings, as compared with six or seven in those of English make, the difference of cost, 0·48 florin as against 4 florins, is too considerable to allow the latter to be used regularly. The crucibles are moulded by hand and dried in chambers heated to between 77° and 104° Fahr., from twenty-five to thirty-days being required for complete drying.

"The steel is classified, according to hardness and percentage of carbon, into the following seven numbers:—

No. 1.—1·8 to 1·5 per cent. of carbon is the hardest class of steel, and one for which there is only an extremely restricted demand.
" 2.—1·5 to 1·3 per cent. of carbon, used for edge-tools, chisels, &c.
" 3.—1·3 to 1·1 per cent. of carbon, used for similar purposes to No. 2, as well as for files and sword-blades.
" 4.—1 per cent. of carbon is a tool steel.
" 5.—0·9 per cent. of carbon is used for finer kinds of springs.
" 6.—0·8 per cent. of carbon is used for coach and buffer springs.
" 7.—0·7 to 0·4 per cent. of carbon is applied for general purposes, such as axles, plates, and agricultural implements.

"The forge-steel scrap and other materials entering into charges are all broken into pieces of two or three cubic inches, and sorted

according to fracture into the different degrees of hardness, the quality being accurately determined by the calorimetric carbon test, applied from time to time. The room in which the selection takes place is provided with five bins for forge steel, five for the better classes of steel waste, and two for plate waste and spiegeleisen. The mixtures, which are carefully weighed out into boxes of the capacity of a single crucible charge, are as follows:—

For No. 1.—Best cast-steel waste, sometimes with an addition of wolfram and carbonaceous matter.
" 2.—20 lbs. forge steel (Nos. 1 and 2), 21 lbs. best steel waste (Nos. 2 and 3), 2 lbs. best Vordenberg spiegeleisen.
" 3.—20 lbs. forge steel (No. 3), 22 lbs. steel waste (Nos. 3 and 4), 2 lbs. of spiegeleisen.
" 4.—20 lbs. cement steel (Nos. 2 and 3), 24 lbs. steel waste (Nos. 3 and 4), 1 lb. of spiegeleisen.
" 5.—20 lbs. of steel waste (Nos. 4 and 5), 20 lbs. puddled steel, 10 lbs. spiegeleisen.
" 6.—20 lbs. steel waste (Nos. 5 and 7), 20 lbs. of puddled steel, 10 lbs. of white Vordenberg pig iron.
" 7.—20 lbs. plate waste, 20 lbs. puddled steel, 10 lbs. white pig iron.

The average loss in melting is from 1 to 2 per cent. of the weight charged. The hardness is determined by a forge test at each cast, and the corresponding numbers are stamped on the ingots.

The furnace, when newly lined, can be worked for a hundred meltings, during which period the cover and fire-bridges must be frequently repaired.

CHAPTER XXIV.

BRASS FOUNDRY.

A BRASS foundry of moderate size and properly designed should consist of the following separate shops:—

Offices.	Dressing room.
Warehouse.	Finishing shop.
Pattern shop and pattern store.	Dipping and colouring room.
Moulding shop.	Lacquering room.
Casting shop.	

The warehouse should be connected to a commodious storeroom, with space for keeping packing-cases, and similar work. The pattern shop and pattern store should be adjacent, if they are distinct, and should be accessible from the warehouse. The pattern store should be lit from the roof, and have plenty of wall space provided with convenient shelves. In the pattern-making shop a side light is desirable, as the men can then better see their work, bench marks, fine lines, and so on.

It is very usual for the moulding and casting shop to be all in one. This does tolerably well where only small work is on hand; but where as many as a dozen moulders are employed, it will generally be found advantageous to separate the shops, in which case the floors should not be on the same level; the casting shop floor should be 2 or 3 feet above that of the moulding shop. By this arrangement the men are enabled to move the flasks from the benches to the floor of the casting shop without stooping. The moulders pass the flasks into the casting shop, through openings in the partitions which divide the two shops. The moulding shop should therefore be narrow, so as to give the men but a short distance to carry the flasks, from the benches to the casting shop floor. There should be ample light, it should come from overhead, and over the benches if possible. These are generally placed along the whole length of the shop, or they may be arranged at right angles to the wall, two being placed back to back.

The sand heap should be centrally placed in the shop, with a shoot from the outside.

The drying stove and core stove are in the moulding shop. These are either heated by fuel, or by means of steam jackets, the latter plan being much the more cleanly and convenient. There should be a water tap and sink in this shop.

The casting shop should be of the same length as the moulding shop, the furnaces being arranged on the opposite side to the moulding shop. This shop must be well ventilated; it should have openings at the floor level, and also in the roof, so as to keep up a current of air.

Stores for coke and for ashes must be provided, and near the spot where the boxes are poured. There should be gratings over which the boxes are to be emptied, the sand going back to the moulding shop by an inclined plane.

The dressing room must be next to the casting shop, so that all castings can be quickly passed in, weighed, cleaned, and dressed before being sent to the warehouse, which should also be near by. A bench, a few vices, and small tools are all that is required in the dressing room.

The finishing shop should be a large, well-lit, and well-ventilated room adjoining the dipping and colouring rooms. These latter must be well supplied with water and sinks, and the *north* light is considered most suitable for them.

The lacquering room must have openings into the finishing shop, and into the warehouse if possible. It must be kept quite free from smoke and dust, be well ventilated, and have a north light.

Modelling and pattern making are both used for brass work, and although these are distinct branches of trade from founding, where work is systematically performed, yet in small country towns there are many workshops where it is of great importance that the same man should be able to execute work and understand the general principles both of modelling and pattern making, as well as of brass founding.

The materials commonly employed for modelling are pipeclay and stucco. The former is used for work of a protracted nature, the latter for straight flat models, which can be finished off at once. Pipeclay, which is decomposed felspar, is made into a putty with

water or glycerine; the glycerine prevents its getting hard for a considerable time.

Almost the only tools required for modelling are made of boxwood, with variously shaped ends. The handles are about six inches long; the sharpest edges are slightly nicked; the others are all more or less blunt.

A horizontal lathe or turning table, like a potter's wheel, is also used for circular pieces.

A few nicely planed boards, of various sizes, are required. On these boards an outline of scroll or other work is drawn, the clay being placed thereon and modelled.

Clay is modelled with the hand and wood tools, mostly by pressure. The clay adheres to wood, or the turning table, when slightly moistened, and requires no other fixing.

Models, made either in clay or wood, and which are intended for immediate use, require to be made larger than the size given, by $\frac{1}{4}$ inch to every foot. Brass castings, under 12 inches in size, shrink about $\frac{1}{8}$ inch to a foot in the mould. Large castings shrink about $\frac{3}{16}$ inch. For this purpose it is best to construct a measure or rule properly divided, so as to save time and calculation.

Should it be required, however, to make a metal pattern from the clay or wood, then the shrinkage will be double, and the model will require to be made $\frac{1}{2}$ inch larger per foot every way, a second measure or rule being required. The real shrinkage is only $\frac{3}{16}$ths, but the other $\frac{1}{16}$th is allowed for finishing. Patterns exactly rectangular do not draw well from the sand; hence all patterns should be made with a taper of at least $\frac{1}{8}$ inch to every foot. Sharp internal angles should be avoided, as they leave an arris on the sand, which requires mending.

It is often necessary, in model making, to take impressions and casts from existing works, which cannot be cut up. In such a case an impression can be taken from it in guttapercha. To soften the guttapercha, either warm it in front of a fire, or place it in hot water, and knead it with the hands to make it of an uniform degree of pliability. After taking the impression, place it in cold water, otherwise the guttapercha will contract on cooling.

Stucco is also used for this purpose, or a mixture consisting of four parts black resin, one part yellow wax.

For complicated patterns, or where cores are required, melt twelve parts glue, to which add three parts treacle.

To prevent wood patterns from absorbing moisture they should be varnished or painted; before use they should be polished with black-lead, as that makes them draw from the sand much more freely.

Mouldings, and the like, can be quickly modelled in long lengths, by sweeping them up in stucco, or other material, by means of a board cut to the required profile, as is done in loam moulding.

A moulding tub is employed for small brass work; it must be very strong, constructed of wood, provided with sliding bars, and a number of 1-inch boards with cross-ends the size of the moulding boxes.

The moulding boxes are similar to those already described, but usually smaller; wooden cramps, fastened by screws and nuts, being made to clasp these boxes lengthwise. In large boxes cross-bars are sometimes cast across them, or the bars may be of wrought iron cast in.

The details of pattern making, moulding, gates, runners, and other foundry details, have already been so fully described for iron, that it will be unnecessary to do more than briefly notice each process in the *brass* foundry, except where any material difference exists.

Ordinary plain work is arranged according to circumstances in the flask. When only one or two castings are required from a pattern, the pattern is wrapped into the flask, that is, the top part being rammed up, a portion of the sand is removed and the pattern inserted, or "rapped in." After sprinkling on some parting sand, the drag is placed on, and facing sand sieved in, after which the ordinary sand is rammed in till the flask is full; then the flasks, top and drag, are turned over so that the drag is lowest, when the top part is taken off and emptied, the face of the drag cleaned again, and dusted with parting sand. After this, the top part is put on, and filled and rammed with facing and ordinary sand, as was done above. The top part is again removed, and the patterns withdrawn. In the process of parting the box and withdrawing the patterns it often occurs that part of the sand is torn away, which in consequence requires to be mended. This process

of mending is a very tedious and costly one. When the moulds have been mended and finished, with gas and air outlets, and gates and runners for the inlet of the metal, the top and drag are put together, closed, and cramped. The mould is then ready to be poured. This mould is called "a green-sand" mould, not having been dried; but if a fine appearance is required, the mould before being closed should be placed in the drying stove. When a large number of any article is required, plate moulding, to which we have already referred at length, is very generally employed.

When an opening, or hollow, has to be left in the interior of a brass casting, a core is inserted in the mould. This consists, as usual, of a properly shaped piece of baked sand, exactly the counterpart of the hole that is desired; this is placed in the mould to prevent the metal or alloy from running into the space. To keep the core in its position it is made a little longer or wider than necessary, so as to have a bearing to rest on at each end. The pattern must have projections on it, so as to leave an impression in the sand to receive the end of the cores. Some cores have only one bearing, as in the case of undercut work, such as fluted columns and ornamental scrollwork. Innumerable modifications in the size and shape of cores exist in every-day practice, and much skill is required in their preparation.

Cores are usually made in boxes, as detailed under moulding, page 227. Where it would be too costly to construct a core-box, it may be dispensed with by moulding the pattern in sand, and casting it solid; a good composition for this purpose is one of plaster of Paris to two of brick-dust, mixed with water. When cast and dry, scrape down to the form of the core.

Cores, like moulds, must have passages in them to allow of the escape of gases, otherwise the casting will almost inevitably be spoilt. A wire must be inserted in the core to make such vent, and be withdrawn just before opening the core-box to remove the core. When cores are large they are supported with iron rods, round which they are built up. To give consistency to the sand used in making cores about one-half should be pure rock sand, which contains a certain amount of clay, but not generally enough, consequently the addition of clay water is necessary to give the sand cohesiveness.

The cores must be dried in a stove, at a temperature not exceeding about 400° Fahr. When dry they should be black-washed, or coated with a mixture of ground charcoal and water, with a little size; this wash must be dried on in the stove, when they are ready for use.

In green-sand moulds it is advisable not to insert the cores till just before pouring, so as to prevent their absorbing moisture.

When a thin brass casting is required, the upper half of the mould is moulded from the opposite impression, and a thin packing piece of clay or other material is placed between the two boxes to keep them the required distance apart. When it is desired to mould small animals, butterflies, leaves, or other delicate and intricate objects which can be consumed by fire, they are suspended in a box, surrounded with a mixture of two of brick dust to one of plaster of Paris, mixed with water. This mould is placed in a furnace to consume the pattern, the remains being shaken out as far as possible, and the metal poured.

The air crucible furnace is that in which brass is usually melted, but when large castings are made, as those required for marine-engine work, or for ecclesiastical furniture, a reverberatory furnace will be found most suitable.

Brassfounders' air furnaces are most frequently sunk below the floor level, the ash-pit being closed with a hinged iron grating. The covers for the furnace top may be either of cast or wrought iron, and should be of a dome shape; there should be a damper in the flue. The interior of the furnace must be lined with fire-bricks set in fire-clay.

The fire-bricks and clay are often contaminated with foreign matters, such as oxide of iron, magnesia, lime, or black-lead, these impurities impair their fire-resisting qualities, and very much shorten the "life" of a furnace. Pure clay should be white, opaque, and oily to the touch, and on analysis should be found to contain a large percentage of silica and alumina. Fire-bricks are made from this clay in the ordinary manner.

It is also most important to have good crucibles, which will neither corrode nor allow liquids and gases to pass through them. They should also be capable of resisting sudden changes of temperature. The crucibles used are either made of black-lead or

Stourbridge clay. The latter are cheaper, but less durable than the black-lead, and require to be carefully hardened by a gradual exposure to high temperatures.

In mixing and pouring brass the least volatile metal should be melted first, the others being plunged under the molten metal with tongs, in small lumps, which must be hot and *quite dry*. The reason that the metal should be hot is that it may remain dry after being dried, as the steam from any slight moisture on it when placed in the melting pot, would probably send the molten metal spirting about in all directions.

Plates LXXVII. and LXXVIII. represent an ordinary melting furnace, but in large works this arrangement is somewhat modified, the ordinary opening to the ash-pit is stopped up, and fan-blast is admitted under the furnace bars; the mouth of the furnace stands about 8 or 10 inches above the floor. The fire-bars should be so arranged, that on moving the front bearer a little forward, the front end of the bars will drop down, so that the furnace can be easily and quickly cleared from ashes and clinkers.

The fuel for the brass furnace is hard coke, which is broken up into lumps the size of a man's fist. The crucible is placed bottom upwards in the fire, so as to get it thoroughly heated; it is then removed with the tongs, turned right side up, and bedded on a slab of fire-clay or a fire-brick, covered over with its lid, and the fire neatly banked up around it. The metal is then placed in the crucible, the cover put on the mouth of the furnace, and the damper is opened to increase the draught; the crucible then remains until the metal is "down." It is usual to throw in with the metal some charcoal dust or broken glass, which floats on the surface of the molten metal, and prevents oxidation. In feeding the metal into the crucible, put the copper or old brass in small pieces until it is nearly full. When this is well melted, add the tin, and mix it well in; then throw in a few small pieces of zinc. If the zinc flares up, throw the rest of it into the pot, stirring it in well; then lift the pot from the furnace, skim off the dross, and pour into the mould.

When placing the zinc in the crucible, drop a piece of borax as large as a walnut into it, this is done to prevent the loss of zinc which goes off in the fumes. If the surface of the hot metal is covered by fine charcoal or borax, which is prevented from burning,

by being renewed, or by broken glass, the loss of zinc is reduced to a minimum.

If, however, when the small trial pieces of zinc are thrown in, they do not flare up, throw on a little coal to make the fire brisk, and cover it over till it comes to a proper heat. Then, as soon as the zinc begins to flare, add the rest. If old brass alone is melted, no tin is required, but a small quantity of zinc. If part copper and part brass, add tin and zinc in proportion to the new copper, with a little extra zinc for the brass.

To prevent volatilization, charcoal, or broken glass, may be spread over the metal whilst being melted.

If the metal is poured too hot the casting will be sand burned, and its colour impaired. The best castings are obtained when the metal is at such a temperature that it will cool quickly. Heavy castings should, therefore, be poured last. The metal must be carefully skimmed. Small work is poured vertically, large work horizontally.

As soon as the brass is poured, it is usual to open the boxes, and to sprinkle the castings with water from the rose of a watering pot, which makes the castings softer than they would otherwise be. When the casting is completed, let the fire-bars drop, clear the furnace from ashes and clinkers, and place the pot amongst them to cool gradually. In a well-arranged foundry, where work requiring a good supply of metal is undertaken, there are generally three or four such furnaces standing in a row, each having a separate flue leading to the chimney, which varies from twenty to forty feet in height, the more lofty it is, the better the draught. Each furnace has a damper to regulate its fire. In order to ensure constant work, it is quite necessary to have several furnaces, to allow of the necessary repairs to the lining, or other parts, being effected to one or other of the furnaces, whilst the remainder are in operation. The lining quickly burns away, and when the space around the crucible becomes larger than 2 or 3 inches, a waste of fuel ensues. Road scrapings are often used for the lining, these contain silica and alumina; or refuse sand from glass grinders, containing flint glass, may be employed. The lining, mixed with water, is laid on like cement, and a brisk fire is at once started in the furnace, which glazes the lining.

The usual charge for a furnace of this description is from 50 to 60 lbs., but of course, when several furnaces can be set to work, a casting of greater weight can be obtained. When, however, a casting of more than two hundredweight is required, it is preferable on the score of economy to melt in a reverberatory furnace, as is done when statues, bells, and works of large dimensions have to be cast.

For small work the gas blast furnace is extremely convenient and economical, it is also very clean in working, and can be placed on an ordinary workshop bench. The cover and pipe over the crucible must be of fire-clay, as the most intense heat can be obtained by this handy little contrivance.

Crucible tongs of various sizes are employed, they should be strong and well pinned together, so as to hold the crucible firmly.

Drying stoves for brass, when large, do not differ from those described in Chapter XVIII.; when small, they consist of small chambers made of sheet iron. These can either be heated by a fire inside, or, what is much better and more cleanly, by steam jackets heated with the exhaust steam from the engine. Where the stove is heated by a fire it may be built of brick with iron doors, but it must be constructed entirely of iron if it is to be heated by steam. Care must be taken to have a proper outlet for the steam.

CHAPTER XXV.

BRONZE FINE-ART WORK—STATUE FOUNDING.

This art has for a long period been skilfully practised in France, and both for design and execution the results obtained by French artists and founders are still unequalled, it is scarcely too much to say they are unapproached. During the reign of Louis XIV., alloys of 91·3 copper, 1 to 2 tin, 5 to 6 zinc, and 1 to 1·5 lead, were used. Another mixture employed was 82·4 copper, 10·3 zinc, 4 tin, 3·2 lead.

Germany has produced a few examples of really artistic bronze castings, for the most part statues, the finest of which, that of Frederick the Great, with its beautiful surrounding figures, at Berlin, is well known in this country from the numerous casts of it to be found in our fine-art galleries.

In England we are so accustomed to the ridicule cast upon our public statues, that it is seldom anyone is to be seen seriously examining their details, although a few certainly deserve something better than this neglect and contempt. But in almost very instance where our statues and monuments are unsatisfactory the artist or designer is to blame, very seldom indeed is the founder in fault.

Wellington, at Hyde Park Corner, who, seen from below, appears a shapeless mass of cloak, surmounted by a cocked hat; Charles James Fox, looking like a fat old man waiting to be shaved, with the hairdresser's cloth round him; these, and many more costly failures, are not the proofs of any want of skill in our bronze foundries, but of the reckless manner in which the public money is disposed of, by trusting such work to incompetent artists; generally indeed these *jobs* are managed by influence, without any pretence at a preliminary competition.

These remarks may seem at first sight too severe, but when it is remembered that England has for a long time held its own in all kinds of brass and bronze work destined for practical purposes,

whilst every effort to produce a grand statue or a noble monument ends in a dismal failure, the time seems come to place the blame on those who deserve it; and to ask whether an artist cannot be found to design the figure of a man which will remain upright without being *supported* by the voluminous folds of a cloak, or the stump of a tree growing into his back; or whether it would not be wiser to leave a bronze casting in its natural colour rather than cover it with gilt, so that man, drapery, and chair formed one glaring, gaudy, dazzling, and incoherent jumble? Art alone is to blame for such errors; it might perhaps be more correct to say the want of art. An artist for this description of work is not only required to possess all the artistic skill of a modeller and sculptor, but must be possessed of a thorough knowledge of the nature and capabilities of the material in which his works are destined to be produced.

Paris and its neighbourhood contain the most famous and the most successful bronze foundries in the world, and anyone who has visited that city must have noticed the number of shops devoted to the sale of the smaller articles of *vertu*, and the beauty and elegance of their contents. The permission to view the works from whence these objects issue, is only obtained with considerable difficulty, and the greatest jealousy exists between the masters as to obtaining the services of skilled and artistic workmen, upon whom principally the fame and success of the foundry depends.

The French Bronze works are usually arranged into departments, which comprise:—

1. Designer's room.
2. Bronze foundry.
3. Chasing shop.
4. Model shop.
5. Marble working shop, provided with apparatus for working marble by hand and machine tools.
6. Enamelling shop.
7. Fitting and mounting shop.
8. Store-room, and gallery for finished work.

M. Collas having improved upon certain old and well-known principles, and perfected a beautiful machine for the automatic reduction or enlargement of solid forms, was enabled to reproduce any bronze to any scale, with perfect accuracy and small cost. Such an invention well deserved the grand medal it obtained at the Paris Exhibition, and is now largely employed by French bronze manufacturers, who can by its means provide their customers with

copies of nearly any famous work of art, at a comparatively small cost.

In the Foundry, if the works generally to be produced are small in size, the moulding is done on benches, and the moulders work *vis-à-vis* at the same bench, which is divided by a longitudinal partition, provided with a shelf for tools. Small and unimportant pieces may be moulded in green sand, large works in loam, but the greater portion of general work is moulded in dry sand. The two sands principally employed are obtained from a place called Fontenay-des-Roses, near Paris; the one is a deep-brown loamy sand, the other is of a light yellow-white tinge. These sands are mixed in proportions carefully regulated according to the nature of the work for which they are intended, and the mixture is reduced to a uniform fineness by being passed between cast-iron rollers. The sand is then damped and sifted.

The moulding boxes are of cast iron, accurately fitted, the edges being planed true.

When the objects are to be finished in the lathe the patterns are sometimes of wood, but most frequently bronze models are made, and are truly finished to the desired form. Many other substances are used for models, such as plaster, wax, fusible metal, porcelain, and glass.

For Facing Sand a mixture of potato starch and charcoal dust, or fine white flour, is used; but charcoal dust is the favourite material.

Sand cores are used for all hollow pieces, unless these are to be cast in loam, or are of a large size; in the latter cases the cores are of loam. In bronze statue casting, the thickness of the metal should be as nearly uniform as possible, otherwise work will be distorted from unequal contraction; bronze contracts considerably on cooling, the extent depends upon the proportions of the constituent metals employed in its composition, and varies from 1 to 2 per cent. This contraction is found to increase in ratios with the size of the casting.

The perfection of bronze work is said to consist in having the mould very highly finished, and obtaining a bright sharp casting, which shall require only a minimum amount of subsequent chasing and tool-work, thus leaving the skin of the casting as far as possible undisturbed.

In the French Fine-Art work the furnace arrangements are such that the moulds and cores are generally dried in furnaces heated by the waste heat from the crucible furnaces. The bronze is melted in clay crucibles, holding between 60 and 70 lbs., with coke for fuel, and a fan-blast. For large work an air-furnace is generally employed.

Best English or Straits tin, and very pure South American copper, which latter is purified by liquation, are the metals employed. A proportion of gates and runners may be added, but this is only done when the proportions and quality of their ingredients are known, and no old bronze guns, old copper or brass, or other material of unknown and variable composition, are ever used, as it is considered impossible to rely upon obtaining a first-rate casting from such uncertain ingredients.

The moulds are placed in cast-iron boxes, which are placed in a naked pit. A reservoir formed of sand with a charcoal facing is employed, into which the contents of the crucibles or air-furnaces are drawn. This reservoir communicates with the main gate of the mould, and as soon as a sufficient quantity of metal is in the reservoir, an iron plug in the bottom is removed, and the metal flows into the mould, from whence the surplus passes off by "rising heads," which are purposely kept small for fear of distorting the casting from too great a pressure.

The gas evolved during the pouring is fired at the rising heads by a torch.

Bronzes which are intended to be coated with enamel, have their surfaces specially prepared for its reception, by what the French artists call *cloisonné*, or partition, work. This process is a somewhat tedious one, and requires great skill on the part of the moulder. The outlines of the design for the enamel are described by small thin partitions of bronze projecting upwards from the main body of the work less than a twenty-fifth part of an inch. Thus the bronze has its surface covered with a network of fine lines, and when the enamel is baked into the shallow cells so formed, the enamel and the bronze partitions are ground and polished to a uniform depth.

These partitions serve two useful purposes, they describe the outlines, and they tend to hold the enamel firmly in position.

In finishing patterns for this class of work, every irregularity in the cells and partition walls has to be cut out, and great care is necessary not to injure the surface.

When such patterns are finished, they represent a considerable value in skilled labour, and are extremely delicate, consequently they are kept covered up on soft cushions, away from danger of accidental damage.

The founding of statues is certainly a very ancient branch of the art, and one in which our ancestors held their own, as the grace and skill of existing specimens abundantly testify. The invention of the Samian artists consisted, in all probability, of running the metal into a mould which contained a centre piece or kernel, to diminish the thickness of the metal by leaving a hollow space in the centre of the statue. The necessity for this kernel is self-evident, for a solid bronze statue would be most costly and cumbersome. Besides, unless the statue is very light it would in many cases be unable to stand. A rearing horse, for instance, could never be upheld by its hind legs if the whole body was composed of solid metal; and to lessen the weight that would otherwise bend and break so slender a support, it is not only necessary that the horse should be hollow, but it must be as light as skilled workmanship can render it. Since the day, therefore, of the Samian artists down to the present day, it has been the constant effort of bronze moulders to lessen the thickness of their statues by increasing the size of the kernel, so as to leave as small a margin as possible for the metal to run down this centre piece and the mould with which it is enveloped.

Among early methods for obtaining this end, the most familiar is known as the cire-perdu, or waste-wax process, which was still in vogue when the present system was introduced, and a comparison between the two will best illustrate the progress now accomplished. The "cire-perdu" process required great care, and could only be carried out effectively by the sculptor or modeller himself. Thus let us suppose, for the sake of simplicity, that the object to be reduced is a portrait bust measuring 4 inches in height and 3 in width. The first step would be to model in "sand," or a mixture of porous cement, the outline of the bust, taking care to make it on every side $\frac{1}{4}$ inch smaller than the size it was designed to give to

the finished statuette. This outline or "core," must be coated up with wax to make up the deficient $\frac{1}{4}$ inch. This much might be accomplished by an ordinary workman, but for the rest the services of the artist are indispensable. With great delicacy of touch he must work up the likeness and texture of his subject on the wax; in fact the expression, the minute lines, all the details of the artist's conception, must be executed in this wax, and it will be seen at once that he alone is competent to carry this out satisfactorily. Were it done by anyone else it would be at the best but a copy of the statuary's conception.

The portrait completed, five or six pieces of wire must be pushed through the wax into the sand outline or core. It is now necessary to coat over the wax with liquid sand, applied most carefully with a fine hair-brush. When a few coats of this sand have been made to adhere to the wax, the statuette is surrounded by an iron frame, and the frame is filled up with sand mixture. The frame is generally about twice the size of the statue. When all is ready, this frame is removed with its contents to a warm place, so that the water may evaporate from the sand and the latter gradually consolidate. Holes must then be cut at one end through the outer sand casing to the wax; after which the frame is subjected to the baking process in a hot oven. The wax of course melts and runs out of the small perforation, leaving a space between the inner core, maintained in its position by the wires mentioned above, and the outer mould, which latter bears the faithful impression of the modelling bestowed on the wax. The holes through which the wax escaped are now used for the purpose of introducing the molten bronze. The metal poured in rapidly fills the space once occupied by the wax, and the work is done. When the metal has had time to cool, the artist anxiously breaks the sand casing away to disentomb his work. Sometimes a successful result awards his pains, but the work is often a failure. The metal has not perhaps filled all the sharper and smaller crevices in the mould, or the presence of damp has impeded the process, or again, the escape of various gases has split the mould; and thus the whole work is in one moment destroyed and must be commenced from the very first stage.

On the other hand, the method now pursued is more scientific, involves less risk, and is consequently less expensive, though it is

still necessary to exercise the greatest skill and judgment. The sculptor need only produce his conception in plaster, and when this is finished, hand it over to the founder, who can undertake the rest of the work without any assistance from the sculptor. The plaster model is forthwith imbedded in the sand contained in an iron frame or moulding box. Thus safely laid out in a soft bed, the workman begins what is called piece-moulding. Taking a small section of the statue, he forces the sand, by striking it gently with a mallet into every fissure and crevice, and thus obtains an accurate impression of that part of the model on which he has been working. Having completed one piece he proceeds with another, till, by putting the pieces together, he can cover that part of the statue which is exposed out of the sand-box. The model is then lifted from its bed, turned round, impressions taken of the other side, and when this is completed the model can be removed uninjured.

The pieces of sections of the sand having the impressions of the model are fitted together in their relative seatings within the two halves of the mould-box. The mould being removed, we have, as it were, two sand inversions, one representing the right and the other the left side of the statue. The moulder then proceeds to make in the impress, a core or facsimile, only a little smaller in size, so that when this is placed within the mould, there should remain all round a margin between the mould and the core equal to about $\frac{3}{16}$ inch in thickness. The core and the pieces which constitute the mould being secured in their respective places, the whole is then exposed to the heat of an oven, so that the moisture may be removed and the sand hardened to receive the metal. Vents for the foul air and gas must also be provided, and runners to enable the metal to penetrate rapidly the margin between the core and outer mould after the bronze has thus been cast. The sculptor may, if he chooses, suggest any improvement to the chaser, who polishes and finishes off the casting. Owing to the intricacy and fineness of the model, it sometimes requires a great number of pieces to make the mould, and several months' work to finish successfully, even a group small enough to be stood upon a mantle-piece. One of the great advantages of this new process is the fact, that if the casting fails, the artist's chalk model, the result perhaps of infinite labour and

of an inspiration which may never be repeated, remains unaltered. A new mould may be taken from it, and the second cast prove a success. The statue may thus also be reproduced as often as desired; while with the old process the artist's work was carried away for ever as the wax melted, and if the cast proved a failure there was no longer any record remaining of the work done and lost.

The process of piece-moulding is largely employed at the foundry of Messrs. H. Young and Co., London, and to this firm we are indebted for the production of some of the best modern fine-art castings. The beautiful lamp standards which adorn the Albert Embankment, on the river Thames, are notable specimens of their skill.

CHAPTER XXVI.

BELL FOUNDING.

The manufacture of bells dates from a very early period; church bells were certainly in use in England in the reign of King Egbert, as the priests were expressly commanded to ring them at certain hours. According to Stowe, bells were first cast in England by Turketel, Abbot of Croyland, Chancellor to Edmund I.; and the first tunable set were put up in Croyland Abbey, about 960.

In early times bell founding, like most of the useful arts, was carried on by the monks; when, however, it became a regular trade, many of the founders carried on their vocation by journeying from place to place, and casting bells quite close to the position they were intended to occupy.

It is improbable that any bells now remain in this country of date prior to the fourteenth century, and of the most ancient of these the age can only be approximately ascertained, as the custom of placing a date and inscription on bells, which is now almost universal, only commenced in the sixteenth century.

The very old bells expand more gradually from crown to rim than the modern ones, which spread out somewhat abruptly towards the mouth. It may also be said that the former are almost invariably of excellent tone, and far superior, as a rule, to those cast in recent times. It has long been popularly supposed that the tone of the older bells was due to an addition of silver to the bell metal, but recent experiments have shown that the presence of silver spoils the tone, in direct proportion to the quantity of silver added. Owing to the number of church bells in our towns, England used formerly to be called *the ringing Island*, although, indeed, Rabelais applies the term *l'Isle sonnante* to Rome. In England bells are usually arranged in peals, whilst on the Continent, especially in Belgium, the churches are provided with chimes of excellent tone, which are either played upon by hand, or by simple mechanism which is arranged to perform certain airs.

Before the Reformation it was usual to cast some religious invocation on the bells; that custom was replaced by the founders placing their trade marks, or some short sentiment or verse, upon the bells, either with or without a date.

The chief reason why so few bells of early date are now to be found in England is, that during the Civil Wars very many were removed from the churches to be cast into cannon; another reason is, that it is usual to remove and destroy old bells for the sake of their metal, when new ones are required.

The largest bells are to be found in Russia; that which was cast in Moscow, in 1736, is said to have weighed 250 tons, and the value of the metal contained in it was estimated at considerably over 66,000*l*., much gold and silver having been thrown in as votive offerings by pious people. This bell was broken the year after it was cast; another, weighing about 110 tons, was cast in 1817, and three other smaller ones have since been added.

No bell at all approaching these in size exists in England; "Big Ben," which was cast for Westminster, in 1856, weighed 15 tons 8½ cwt., and this being cracked, was replaced in 1858, by one about 2 tons lighter.

"Big Ben" was, and its successor, "St. Stephen," is, the largest bell in England. "Big Ben" was so named after Sir Benjamin Hall, then Chief Commissioner of Works; it was cast at Houghton-le Spring, Durham, by Messrs. Warner, at an expense of 3344*l*. The alloy used was composed of 22 parts of copper to 7 parts tin. Its diameter was 9 feet 5½ inches; height, 7 feet 10½ inches. The clapper weighed 12 cwt.

In October, 1857, it was discovered that "Big Ben" was cracked; it was consequently removed and broken up. A new bell was cast by Messrs. Mears with the same metal. This bell, called "St. Stephen," weighs 13 tons 10¾ cwt.; its diameter is 9 feet 6 inches; its height, 7 feet 10 inches; the clapper only weighs 6 cwt., about half the weight of the former clapper.

This bell was struck for the first time on the 18th November, 1858, and less than a year elapsed before it also was found to be cracked. The note of the bell is E natural, the quarter bells being G B E F, the weight of the fourth quarter bell being 4 tons.

Many bells have been successfully cast abroad, closely approach-

ing the weights of "Big Ben" and "St. Stephen," but in England, except the bell at York, which weighs 10 tons 15 cwt., the next largest is scarcely half the weight of "Big Ben," and the bell of St. Paul's Cathedral only weighs 5 tons 4 cwt.; this was cast as early as 1716, it is 10 feet diameter, the clapper weighs 180 lbs. As the two bells at Westminster may be looked upon as decided and costly failures, it would appear that the art of bell founding on a *large scale* is not so well understood in England as it is on the Continent, and it is certain that in many instances little or no attention is paid to the musical tone, for except where the bells are arranged in regular peals, church bells in England are almost universally clanging, monotonous nuisances: fortunately, they are usually so badly designed that their noise does not reach far. It is not our object, however, to enlarge upon the artistic merits of bells, except in so far as they may be dependent upon the form of the bell, and the nature of the alloy of which they are cast.

In the list of alloys used for bell casting, and for other instruments, such as gongs, and cymbals intended to give forth sound, it will be seen that the chief ingredient is copper, to which tin is added, in proportions which vary according to the tone required, for upon the latter metal depends the peculiar tone of the casting.

In 1857, E. B. Denison read a paper on the "Great Bell of Westminster," at the Royal Institution, in which he gave the results of numerous experiments on the shape of bells, and the composition of bell metal.

The object in view being to obtain the best bell that can be made of a certain weight, to give a combination of the most powerful and most pleasing sound, the shape and composition of metal have to be settled. As to the *depth* of note, he says, any depth of note can be got from a bell of a given weight, by making the bell larger, thinner, and of course worse, as the sound becomes thin and poor, and cannot be heard at any great distance.

The French shape for bells is not considered so good as the English standard, nor is the mixture of metal they employ considered correct.

The shape adopted for the Westminster bell was something between the shape of the great bell of Notre Dame in Paris, and that of the great bell at Bow.

The exact height of the bell does not appear to be of great im-

portance; foreign bells are usually higher than English ones, which vary from two-thirds to three-fourths the diameter, although there are some higher ones; the vertical height inside of the bells at Westminster is $\frac{17}{24}$ of the diameter.

In a bell of the usual proportions the thickness of the upper or thin part is one-third of the *sound bow*, or thickest part. As to the thickness of the sound bow itself, which is often spoken of simply as the *thickness* of the bell, large bells of a peal are sometimes made as thin as $\frac{1}{16}$th of the diameter, and the small ones as thick as $\frac{1}{10}$th of the diameter; the most effective proportion is from $\frac{D}{12}$ to $\frac{D}{13}$.

In casting peals of bells it is necessary to take rather a wider range, in order to prevent the treble being so small and weak as to be overpowered by the tenor, though care must be taken not to run into the opposite extreme, and make the large bells too thin.

The thickness of the Westminster bell ("Big Ben") was $9\frac{3}{8}$ inches, or about $\frac{1}{12}$th the diameter, 9 feet $5\frac{1}{2}$ inches; the waist was $3\frac{1}{8}$ inches, or one-third of the sound bow; the width at the top inside was one-half the width at the mouth.

In calculating the sizes of bells to produce particular notes, and assuming that eight bells are made of similar material, and their sections exactly similar figures, in the mathematical sense, they will sound the eight notes of the diatonic scale, if all their dimensions are in these proportions: 60, $53\frac{1}{3}$, 48, 45, 40, 36, 32, 30, which are merely convenient figures for representing the inverse proportions of the times of vibration belonging to the eight notes of the scale. So that if it is required to make a bell a fifth above a given one, it must be two-thirds of the size in every dimension, unless it is intended to vary the proportion of thickness to diameter, for the same rule then no longer holds, as a thinner bell will give the same note with a less diameter.

The reason is, that according to the general law of vibrating plates or springs, the time of vibration of similar bells varies as $\frac{\text{thickness}}{\text{diameter}}$ 2. When the bells are also completely similar solids, the thickness itself varies as the diameter, and then the time of vibration may be said simply to vary inversely as the diameter.

The weights of bells of similar figures vary as the cubes of their diameters, and may be nearly enough represented by the figures 216, 152, 110, 91, 64, 46, 33, 27. The exact tune of a set of bells, as they come out of the moulds, is a secondary consideration to their tone or quality of sound, because the notes can be altered a little either way by cutting, but the quality of the tone will remain the same for ever; except that it gets louder for the first two or three years that the bell is used, probably from the particles arranging themselves more completely in a crystalline order under the hammering, as is well known to take place.

The designing of bells is regulated by certain fixed rules, derived from experience, and which are handed down from one generation of bell-founders to another; some makers have their own peculiar mixtures of metal and design of bell, to which they attach particular importance and secrecy, but it is doubtful whether any real advantage has been attained, either in tone or durability, by any of these secret processes, as compared with bells carefully designed and cast with proper precautions, and a thoroughly good metal, on the ordinary plan.

The weight of the clapper for "Big Ben" was much greater than usual, in proportion to the weight of the bell; whether it was wise to design it so, or not, is a question which is not easy to decide, but in the next bell, "St. Stephen," the clapper was only made half the weight. The reasons given for its unusual size, are that it was found that an increase of sound could be obtained from the bell by increasing the weight of the clapper up to 13 cwt., or about $\frac{1}{27}$th of the weight of the bell, which is a little higher than the proportions existing in some of the large foreign bells, and two or three times as high as the usual English proportion.

The weight of a clapper is limited by two considerations, the strength of the bell and useful effect, for there is always a limit beyond which no more sound can be got from a bell by increasing the weight of the clapper. The result was satisfactory in one respect, as the body of sound given out by "Big Ben" was very different to that obtained from other large bells having only small light clappers. This result is one of the tests by which to determine the value of a bell, as although almost any depth of note can be got out of a bell of any weight by making it thin enough, and

a small bell of a few hundredweight will sound almost the same note as one weighing several tons, at a short distance the sound becomes thin and poor, and is inaudible long before the larger bell, if the latter be properly designed. As an example of this may be cited the 29-cwt. bell, which was exhibited in 1851; it was hemispherical in form, and sounded nearly the same note as "Big Ben," and yet it could not be heard so far as a 3-cwt. bell of the usual and correct form. And a Chinese gong, which also gives a deep note and a loud noise, can only be heard at a comparatively slight distance, showing with what a small weight of metal deep tones can be obtained, although it is true that a gong differs from a bell, because it can only be roused into full vibration by a repetition of soft blows. In casting gongs, 4 copper to 1 of tin, they are allowed to cool suddenly, the metal is then rendered malleable; but the art, simple as it would appear, of making good gongs appears to be possessed by the Chinese alone.

The usual mode of hanging large bells is to cast six ears or loops on the top or crown of the bell; these are called *canons*, through which iron hooks and straps are put to fasten the bell to the stock.

Small bells may be hung quite securely by a single canon, or plug with a hole in it, like a common hand-bell.

This method of hanging by canons is objectionable no doubt, as they must always be the weakest part of the casting, from being nearest the top; and in practice it is found that they frequently break, and have to be replaced by iron bolts put through holes drilled in the crown. It is also difficult to turn the bell in the stock, to present a new surface to the clapper when it is worn thin in one place. These disadvantages were avoided in the Westminster bells, by casting on a very short thick hollow neck with a strong flange round the top, which could be fastened to the stock by bolts with hooked ends. By this arrangement the bell is held by a large section of its own metal, and can at any time be shifted round by slackening the bolts. If a clapper is to be used, it can be hung upon a separate bolt, passing through the hole in the neck, and through the stock, and secured above.

When only clock hammers are employed to strike on bells, the wear is so small, that the facility for turning the bells is of secondary

importance. But this plan, which was designed by Mr. Denison, has the great recommendation of strength, and would probably have been largely adopted but for the loss of the *canons*, which are regarded by the founders as an ornamental finish to bells, upon which they rather pride themselves.

The following is a list of several of the largest bells known, the weights of the two Russian bells are not over-estimated, for the thickness and height are well known, and there are several other bells, mentioned in works on Russia, all of great weight, from which it appears that the Russians have surpassed all other nations in the magnitude of their scale of bell founding. Many large bells are also known to exist in China, but they are of a totally different form, and no reliable information exists from which to give details of their composition and mode of construction.

TABLE XIX.—LIST OF LARGE BELLS.

	Weight.	Diameter.	Thickness.	Note.	Clapper or Hammer.
	tons cwt.	ft. in.	in.		
Moscow, 1736; broken 1737..	250 (?)	22 8	23	..	..
Another, 1817	110 (?)	18 0	..	..	$\frac{1}{15}$ of bell
Three others	16 to 31	..	..	..	..
Novogorod	31 0	..	..	..	..
Olmutz	17 18	..	..	..	..
Vienna, 1711	17 14	9 10	..	..	..
Westminster, 1856 ..	15 8½	9 5½	9⅞	E	12 cwt.
Erfurt, 1497	13 15	8 7½	..	F	..
Paris, 1680..	12 16	8 7	7½	..	6½ cwt.
Montreal, 1847	12 15	8 7	8½	F	..
Cologne, 1448	11 3	7 11	..	G	..
Breslau, 1507	11 0	..	..	..	..
Gorlitz	10 17	..	..	..	..
York, 1845..	10 15	8 4	8	F sharp	4 cwt.
Bruges, 1680	10 5	..	..	G	..
St. Peter's, Rome ..	8 0	..	..	..	..
Oxford, 1680	7 12	7 0	6½	..	80 lbs.
Lucerne, 1636	7 11	..	..	G	..
Halberstadt, 1457 ..	7 10	..	..	..	..
Antwerp	7 8	..	..	..	..
Brussels	7 1½	..	..	G sharp	..
Dantzic, 1453	6 1	..	..	..	..
Lincoln, 1834	5 8	6 10½	6	A	150 lbs.
St. Paul's, 1716.. ..	5 4	6 9	..	A	180 „
Ghent	4 18	..	..	..	..
Boulogne (new).. ..	4 18	..	..	..	..
Old Lincoln, 1610 ..	4 8	6 3½	..	B flat	..
Fourth quarter bell, Westminster, 1857	4 0	6 0	5¾	B	..

Concerning the composition of bell metal, it is well known to consist of from 5 to 3 of copper to 1 of tin; experiments have been made to ascertain whether there is any other metal or alloy which would answer better, or as well, and cheaper. The metals that have been suggested are aluminum, either pure or alloyed with copper; cast steel; union metal, consisting of iron and tin, and perhaps glass, might be added. The first is at present quite out of the question, as it is enormously expensive. Steel bells, though they might be made cheaper than in bell metal, are exceedingly harsh and unpleasant in tone. Much the same may be said of the iron and tin alloy, of which there was a large bell in the Exhibition of 1851. It is scarcely necessary to refer to glass, because its brittleness is enough to disqualify it for use in bells; but, besides that, the sound is very weak, compared with a bell-metal bell of the same size, or even the same weight, and of course much smaller.

As regards silver, that is a purely poetical and not a chemical ingredient of bell metal; there is no foundation whatever for the vulgar notion that it was commonly used in old bells, nor the least reason to believe that it would do any good. This may easily be judged of from the fact that a silver cup makes a rather worse bell than a cast-iron saucepan.

Dr. Percy cast several small bells of various alloys with the following results:—

Iron, 95 Antimony, 5	Not so good as copper and tin alloy either in tone or strength.
Copper, 88·65 Phosphorus, 11·35	A very hard alloy, capable of a fine polish, but more brittle than bell metal, and inferior in sound even to the iron alloys.
Copper, 90·14 Aluminum, 9·86	This exceeds bell metal in strength and toughness, and polishes like gold, but for tone it will not stand against bell metal.
Brass	This makes a better bell than the last-named alloys, but very inferior to bell metal.

M. Ste. C. Deville, of Paris, cast a bell of pure aluminum; in form it was a reproduction, on a small scale, of the Westminster bell, reduced to 6 inches diameter; the surface was turned, and every care taken to produce as perfect an aluminum bell as possible; but this proved to be quite as objectionable in tone as any of the alloys above named, whilst of course the cost would have put the

metal out of the question commercially, even if it had given a good musical result.

Having, therefore, brought the subject back to the copper and tin alloy as the best suited for bells, the starting point for further inquiry is, what are the best proportions to use in order to obtain the strongest, clearest, and best sound possible?

They have varied from something less than 3 to something more than 4 of copper to 1 of tin, even disregarding the bad bells of modern times, some of which contain no more than 10 per cent. of tin, and no less than 10 per cent. of zinc, lead, and iron adulterations. Upon trial it was found, however, that the best metal for the purpose is that which has the highest specific gravity of all the mixtures of copper and tin. Copper, as now smelted, will not carry so much tin as the old copper did without making the alloy too brittle to be safely used. The 3 to 1 alloy, even when melted twice over, had a conchoidal fracture like glass, and was very much more brittle than 22 to 7 twice melted, or 7 to 2 once melted. The metal used for the Westminster bells was 22 to 7 *twice* melted, or 24·1 of tin and 75·86 of copper.

This 22 to 7 mixture, or even 3½ to 1, which is probably the best proportion to use for bells made at *one* melting, is a much "higher" metal than the modern bell-founders, either English or French, generally use. As there is no great difference in the prices of the two metals, the reason why they prefer the lower quantity of tin is, that it makes the bells softer, and therefore easier to cut for tuning, which is obviously a very insufficient reason. It would therefore be advisable to stipulate, when ordering bells, that the metal shall, when analyzed, contain not less than 21 per cent. of tin, or more than 2 per cent. of anything but copper and tin.

TABLE XX.—ANALYSES OF SEVERAL BELL METALS.

	Rouen.	Gisors.	York.	Lincoln.	Westminster.	
			Old Peal.	1610.	Top.	Bottom.
Copper	71·	72·4	72·76	74·7	75·31	75·07
Tin (with Antimony)	26·	24·2	25·39	23·11	24·37	24·7
Iron	1·2	..	·33	·09	·11	·12
Zinc	1·8	1·	..	traces	..	..
Lead	..	·4	1·77	1·16	traces	traces
Nickel	..	..	·85	·58	..	..
Specific gravity ..	..	..	8·76	8·78	8·847	8·869 8·94

It will be noticed that in the Westminster bell the specific gravity was higher than in the others, and it is considered that the specific gravity of bell metal should not be lower than 8·7.

Small bells are generally moulded in sand from a metal or wooden pattern, and the sand mould is dried in a stove. Having before described such moulding, it will not be necessary to enlarge here upon the casting of small bells, of less weight than, say, 112 lbs. The most important point in the art of bell founding is the proper form to give a bell to obtain the desired tone, which is also dependent upon the metal used.

Large bells are moulded in loam, in the same way as the large pan shown in Fig. 1, Plate XLV. The core is built in brick on an iron platform, which must have nugs in case the mould is made above ground. This brick core is covered with $\frac{3}{4}$ inch or 1 inch thick of hair-loam, and the last surface washing is given by a finely ground composition of clay and brick-dust. This latter is mixed with an extract of horse-dung, to which is added a little sal-ammonia. Upon the core the "thickness" is laid in loam-sand, but the thickness is again washed with fine clay to give it a smooth surface. Ornaments which have been previously moulded, either in wax, wood, or metal, are now attached by means of wax, glue, or any other kind of cement. If the ornaments are of such a nature as to prevent the lifting of the cope without them, for the cope cannot be divided, the ornaments are fastened to the thickness by tallow, or a mixture of tallow and wax. A little heat given to the mould will melt the tallow, after which the ornaments adhere to the cope, from which they may be removed when the cope is lifted off the core. The thickness must be well polished; and, as no coal can be used for parting, the whole is slightly dusted over with wood ashes. The parting between the core and the thickness is also made with ashes. The cope is laid on at first by means of a paint-brush, the paint consisting of clay and ground bricks, made thin by horse-water. This coating is to be thin and fine; upon it hair-loam, and finally straw-loam is laid.

The crown of the bell is moulded over a wood pattern, after the spindle is removed. The iron or steel staple for the hammer is set in the core, into the hollow left by the spindle. It projects into the thickness, so as to be cast into the metal. The facing of the mould ought to be finished when the cope is lifted off. Small

defects may occur, and are, if not too large, left as they are; the excess of metal in those places is chiselled off after the bell is cast. All that can be done in polishing the facing of the mould is to give it a uniform dusting of ashes. When the mould is perfectly dry, it is put together for casting. The core may be filled with sand, if preferred, but there is no harm done if it is left open; for bell metal does not generate much gas, and there is no danger of an explosion. The cope is in some measure secured by iron, but its chief security is in the strong, well-rammed sand of the pit. The cast-gate is on the top of the bell, either on the crown, or, if the latter is ornamented, on one side of it. Flow-gates are of no use here, the metal must be clean before it enters the mould: there is no danger of sullage.

The mode employed in casting "Big Ben" is thus described: The metal was twice melted; it was first run into ingots of bell metal in a common furnace, and then these ingots were melted and run into the mould from a reverberatory furnace. The ingots were only in the reverberatory furnace 2½ hours before the metal was ready for running, and the whole sixteen tons were run into the mould in five minutes, quick running being considered essential for the production of a sound casting. In the moulding Messrs. Warner proceeded in a different way from that usually adopted.

First of all, a hollow *core* was built of bricks and straw and clay, and made to fit the inside of the bell by being swept over with a wooden pattern turning on a vertical axis through the middle of the core. For bells of a moderate size, they keep a number of different-sized cores of cast iron, instead of building them up of bricks, and the iron cores are covered with loam. These iron cores are easily lifted into a furnace to be dried and heated, whereas the brick ones must have a fire lighted within them. But the great difference in their process is with regard to the *cope*. Generally, a clay bell is made on the top and outside of the core, the outside form being formed by the use of another sweep of the exact profile of the outside of the bell, and turning on the upright spindle as before. When this clay bell is dry, a third fabric of clay and straw is laid on the outside of the clay bell, and this, as is well known, is called the cope. When it is dry, it is lifted up, and the clay bell broken away. The cope is then lowered on to its seat

again, and the metal is poured into the cavity previously occupied by the clay bell. This is a somewhat tedious process, and one by no means certain in its results, as, unless the greatest care is exercised in placing the cope on again, after being lifted, one side of the bell will be cast thicker than the other. And the error is of course multiplied, for if the cope is put on, say, one-eighth of an inch to one side, one side will be one-eighth too thin, and the other side one-eighth too thick, so that one side will be a quarter of an inch thicker than the opposite side.

Messrs. Warner's plan was to make the cope of iron larger than would fit the bell; this was lined with the casting loam, turned true by means of an *inside* instead of an outside sweep, and the junction being between an iron plate at the bottom of the core, and the flange at the bottom of the cope, they could be fitted together more accurately than the clay core and cope could be, and, moreover, bolted together, so as to resist the bursting pressure of the melted metal, instead of having to rely merely on the sand with which the pit is filled, and such weights as might be placed upon it. The core and cope were both made very hot before the pit was closed in with sand; for that was necessary to prevent too rapid cooling, which makes bell metal soft—indeed, if the cooling is very rapid, it will make the metal malleable.

The bell was kept in the casting pit twelve days before the sand was taken out, and even then the cope was too hot to touch, and it was left two days more before it was taken off.

In reference to the composition of the alloy used in "Big Ben," it is only just to state that the Warners did not consider 7 to 22 correct proportions for the alloy, and only adopted those proportions by express direction. They say that they have never adopted that mixture for any large bells, the construction of which has been left in their hands, and that had the original "Big Ben" been formed of the usual mixture, 1 of tin to 3¼ copper, and been struck with a clapper weighing from 5 to 6 cwt., instead of one of 13 cwt., and had it not been allowed to come into contact while in a state of vibration from the action of the clapper with the ponderous experimental clock hammer fixed on the outside, the probability is a second bell would never have been required.

That Warner and Sons did object to using so much tin in the

alloy for fear of making it too brittle, Mr. E. B. Denison admitted when describing the bell; but he stated his opinion that if it was properly cast, the alloy ordered would be found satisfactory.

Whether the fault of the bell was to be found in the composition of the alloy, the weight of the clapper, or the form of that bell, it is now impossible to discover, but the manufacturers seem to have foreseen some trouble with it; and, as they have always been very successful in bell casting, it would no doubt have been good policy to have left them free to settle the proportion of the metals, which should probably vary with the size and weight of the bell required.

Messrs. Warner cast the fine large bell for the Town Hall, Leeds, which weighs over 4 tons, and the Westminster quarter bells, which are of the following dimensions, weights, and notes:—

	Size.	Weight.				Note.
		tons	cwt.	qrs.	lbs.	
1st	45-in. diameter	0	21	0	0	A
2nd	48 "	0	26	0	0	G
3rd	54 "	0	35	1	6	F
4th	72 "	3	17	1	24	C

The following scale gives the average weight of a few peals of bells, of such sizes and proportions as are recommended by Messrs. Warner and Sons, in their 'Notes on Bells':—

TABLE XXI.—PEALS OF BELLS.

Peals of 3.							Peals of 5.						
Weight of Tenor.			Note.	Weight of Peals.			Weight of Tenor.			Note.	Weight of Peals.		
cwt.	qrs.	lbs.		cwt.	qrs.	lbs.	cwt.	qrs.	lbs.		cwt.	qrs.	lbs.
3	1	0	F sharp	8	1	0	6	0	0	C	23	2	0
3	3	12	E	9	2	14	9	0	0	B fla	30	0	0
4	3	0	E flat	12	0	0	10	2	0	A	32	2	0
5	1	0	D	13	2	0	12	0	0	G sharp	39	0	0
5	2	0	C sharp	15	0	0	13	0	0	G	40	0	0
6	0	0	C	16	2	0	15	0	0	F sharp	57	0	0
Peals of 4.							Peals of 6.						
5	0	0	E flat	16	0	0	9	2	0	B flat	35	0	0
5	1	0	D	17	0	0	10	2	0	A	40	0	0
6	0	0	C	19	2	0	11	2	0	G sharp	42	0	0
10	0	0	A	28	0	0	13	2	0	G	50	0	0
12	2	0	G	36	0	0	16	0	0	F	60	0	0
15	0	0	F sharp	42	0	0	18	0	0	E	65	0	0

PEALS OF 8.

Weight of Tenor.			Note.	Weight of Peals.		
cwt.	qrs.	lbs.		cwt.	qrs.	lbs.
13	2	0	G	60	0	0
15	0	0	F sharp	68	0	0
17	3	0	E	75	2	0
20	0	0	E	85	0	0
25	0	0	E flat	100	0	0
30	1	0	E flat	111	2	0

An article upon this subject, which may be referred to with advantage, appeared some two or three years since in Spons' 'Dictionary of Engineering.' This showed distinctly the two modes of tracing the outline of a bell.

CHAPTER XXVII.

CLEANING AND DRESSING CASTINGS.

The casting in foundries is generally performed in the afternoon, so as to make it the last business of the day. This time is chiefly selected to escape the heat of the hot sand after casting, which will then cool during the night. After casting, the castings are removed, and the moulding boxes piled in a corner of the building, so as to be handy for the next day's work; water is sprinkled over the sand, it is then shovelled over, mixed, and thrown in heaps, where it remains during the night. If the latter work has been properly performed, the sand will be of a proper and uniform dampness the next morning. Each moulder takes charge of his own sand, and but little practice is required to learn the proper amount of water to be used in damping the sand.

When the metal of a cast is so far cooled as to be strong enough to bear removal, the moulds are taken apart, and the sand or loam is removed from the casting. Small castings require but a few minutes to cool, while heavier casts take hours and even days. A massive casting, such as a forge-hammer of five tons weight, will take twenty-four hours cooling in a green, and forty-eight hours in a dry mould. The excrescences, fins, spurs, and all ragged edges, which may happen to have been formed in the partings or core-joints are broken off as soon as the cast is removed from the mould. The gates are, at the same time, broken off by the moulder; it requires some degree of skill to break a gate off smooth. Heavy castings are chained to a crane and hoisted by it. Very heavy castings require the united strength of two and more cranes. Small castings are removed from their moulds by tongs; one, two, or more persons taking hold of a casting at the same time, carry it to a place termed the fettling shop, designed for the reception of hot castings. Projections which cannot be removed in the foundry, are chiselled and chipped off in the yard, or in the

fettling shop where the casting is roughly prepared for further work. Heavy cores, and particularly hard cores, are removed in the foundry before the casting is entirely cold.

The cleansing of castings is a simple operation in an iron foundry where common castings are made; any workman is fit to trim a coarse casting, or scour it. The first is done by means of chisels or sharp hammers; the latter, with dull, coarse files, which have been used and rejected by machinists. Cast-iron files are also used for the latter purpose. The trimming and cleansing of valuable castings, such as statues or ornaments of art, is not so easily performed. An unskilful workman can easily spoil a whole casting in unskilfully chipping or trimming it. This kind of work is therefore generally entrusted to skilled workmen, and on such articles as statues, the artist himself generally works out the details of the more important points.

Grindstones are largely used in fettling, the stones being a variety of sandstone commonly obtained from coal districts. They should be of a hard, close-grained, sharp quality, free from veins, and uniform in colour. The stones are generally driven by steam-power, and when, as is frequently the case, they run at a high velocity, they are very dangerous, from their liability to crack asunder. To decrease this danger as much as possible it is usual to apply rings or plates of iron to the sides of the stones; these are bolted on, some soft substance, such as felt, being placed between the heads of the bolts and the stones. Dry grinding cuts slowly, and creates considerable dust, but leaves a smooth skin. Wet grinding cuts quickly, and prevents the grain of the stone from becoming choked with particles of metal.

Neither files or grindstones fettle so well as emery wheels, which are formed of emery of requisite coarseness, mixed with a cementing material. Plates LXXV. and LXXVI. illustrate three sizes of these emery wheels, fitted on to machine frames suitable to the class of work they are intended to operate upon. They each consist of a main spindle running in bearings, and having at either end a grinding wheel and rests. In the centre are the pulleys necessary to transmit the power for running the wheels. The machines illustrated are those made by Slack, of Manchester; Figs. 1 and 2, Plate LXXV. being of one suitable for light work and general

2 B

brassfounder's use; the wheel is 12 inches in diameter, and from 1 inch to 1¼ inch thick. Fig. 3 is of a very powerful machine, adapted for large castings, such as the framing of machinery and the like; the wheels are 36 inches in diameter and 3 inches thick. Figs. 1 and 2, Plate LXXVI. are of a machine specially designed for cleaning the teeth of wheels, suitable mechanical arrangements being made for the support and rotation of the wheel under operation.

The cementing material employed in Ransome's emery wheels is an insoluble silicate, a substance of hardness approaching to flint; and which, by a curious chemical process, is formed within the substance of the block or wheel, there being no means of effecting its direct use.

This cementing material is so strong, that if a block of emery composition made with it be broken, it will be found to have fractured through the grains of emery, and not by pulling them out of their matrix. It is so hard as to cut well in itself, and yet sufficiently softer than emery to wear away faster, and thus avoid the glazing otherwise inevitable. The cement being insoluble in water, enables blocks prepared with it to be used either wet or dry, although the latter way is in most cases preferable.

Small blocks of consolidated emery may be used with great advantage by hand; but of course the proper result is obtained when the form of a circular disc is adopted, and the same rotated at a high speed. Under these conditions the durability and cutting powers of the material are extraordinary, experience having proved that minutes with the wheel will do the work of hours with the file or chisel. A revolving wheel cannot go into corners, or do every variety of work, but an immense deal may be done, and the saving of both time and tools is very great.

Ransome's emery wheels are much esteemed in English foundries, and from the circular of the makers, A. and H. Bateman and Co. of Greenwich, we give the following practical remarks, which apply generally to emery wheels, on their use:—

"It is well to run a coarse and a fine wheel at opposite ends of the same spindle, doing the rough work on the former and finishing up on the latter. Far more work can be got out of the wheels by applying the work lightly to them, than by pressing or crowding

it; the latter only heats the metal, makes the wheel glaze, and often go out of truth.

"Speed has a great deal to do with result; from considerable experience, a surface speed of 4000 to 4500 feet per minute, say 1350 revolutions of the spindle for a 12-inch wheel, is recommended, although a thick wheel may be run one-third faster with advantage, and good work may be got out of a slower speed.

"A foundation for the machine, good enough for slow speeds, will not do for high ones. Any vibration or tremor while at work is certain to produce bad results. It is not enough to screw a spindle firmly to a bench or table, the latter must itself be firm and rigid. In self-contained machines, a good concrete foundation is necessary; the expense will not be grudged, when the results are compared with those obtained from a machine on a shaky foundation. It must be remembered, that a large amount of centrifugal force is developed in a disc revolving many hundred times in a minute, and this must be met by firm foundations, and proper screwing up of the washers and side plates. Too much care cannot be taken on these points."

To A. and H. Bateman and Co. are also due the subjoined practical suggestions:—

"1. Examine emery wheels and machinery at least once a day.

"2. Remedy any defects at once, and on no account go on working with anything out of order. If a machine vibrates, add or alter requisite fittings. If a wheel is chipped or out of truth, true it with a black diamond. This may be done while running at full speed, care being taken to touch the wheel *very lightly*. After trueing, the wheel will be dull; rough it by running it against a piece of copper, or a piece of hard coke. Do this frequently; it makes work pleasanter, and wastes the wheel far less than waiting until it is very much 'out.'

"3. Never let the spindle jump or get hot, either will injure the wheel and produce bad work.

"4. See that side plates fit the spindle, and are fairly true. Screw up firmly, but not so tight as to crush the wheel. Do not use too long a spanner, it is difficult to estimate the force applied by means of a screw and long lever.

"5. Be careful to run the wheels at about the indicated speed;

they wear out quicker if run much slower, and are apt to go out of truth, and an unnecessary risk is run if the speed be too great. Ascertain the speed by means of a counter. Calculation by size of pulleys is not very reliable, owing to the difficulty of making proper allowance for 'slip.'

"6. If working with water, let it be applied close to the work, through a small orifice in a pipe under some pressure, either from the main, or from an elevated cistern. The wind caused by the wheel will otherwise tend to blow the water away. If too much is used it will fly off and cause inconvenience. Generally, working dry will be found preferable, but for tools and small work water is necessary.

"7. With tools and small work, hold in the right hand and press near the end with some of the fingers of the left hand. The moment the heat becomes uncomfortable, dip the work in water standing by, and then replace it on the wheel dripping, it not being necessary to dry it. Heat that will not hurt the fingers, will not injure the temper of the steel.

"8. If a wheel breaks, nearly if not all the fragments will fly in the line of rotation. In grinding, therefore, stand as clear as possible of this line, to avoid injury in case of accident. Railway trains sometimes come to grief. An emery wheel running the same speed may do the same, but will not with proper care.

"9. Mount the wheels with the washers supplied, and do not strip them off and put on others.

"10. Most important of all, remember that *fair working gives best work*. Forcing work against a wheel injures both, causes risk of accident, hastens the wear of the wheel, frequently causes glazing, which never happens with proper grinding, and is sure to wear a wheel untrue and involve very frequent trueing up."

There is but one limit to the use of emery wheels for fettling castings, and that is the size and weight of the castings. All castings, whether iron or brass, not too heavy or unshapely to be readily handled, should be fettled by the solid emery wheels, and it is placed beyond dispute by the experience of years, that this plan is cheaper and more practical than any other.

We see little reason to doubt that the solid wheel will in time entirely displace the grindstone. There is really no advantage in

the very large size of grindstones, and the great variation between their maximum and minimum size, causes much inconvenience to the workmen. The size of emery wheels is such that they occupy but little space, and are mounted with the greatest ease and speed. They are so strong that they can be run at an immense speed, and being composed of angular grains of a mineral only inferior in hardness to a diamond, they cut much more rapidly than grindstones, whose uneven texture is mainly caused by round and waterworn particles of silica. While the stones have to be roughed and picked from time to time, no really good emery wheel ever requires such treatment, presenting always a fresh, free, sharp-cutting surface. In consequence of the hardness of the surface and the very high speed, the work needs to be lightly touched to the wheel, and the selection of heavy men as grinders is done away with, as are also the swinging boards, housings, and appliances for getting pressure. Owing to the moderate size of the wheels, they can be easily turned with diamond tools, and thus always revolve as perfect circles, instead of becoming eccentric as the stones do.

CHAPTER XXVIII.

EXAMPLES OF FOUNDRIES; COST OF MOULDING AND CASTING.

The planning of a foundry is dependant upon so many varied circumstances, that we cannot do more here than mention a few of the chief points demanding attention. We may remark that a well laid-out foundry will always return greater profits to its proprietor than would otherwise be the case; and it must be remembered, that the construction of such works is peculiarly the province of an engineer who is familiar with the operations to be conducted therein. The foundry should, where possible, be built near some navigable stream, and adjacent to good railway depôts. The space appropriated to the works should be ample, so as to allow of future extension, and the buildings may be of brick, with hip roofs, and amply lighted.

Stores for the raw materials should be roofed in, and near the furnace-house. Much waste is occasioned by leaving the pig iron, coke, sand, and the like, unprotected from the rain, besides this practice being very unsightly and untidy.

The materials for core making and loam work should be stored in a separate shed, close to the loam shop, where the mills for grinding the loam should, if possible, be located.

The fettling shed should always be under cover, as the castings, when run there to be cleaned, are hot, and will suffer severely from unequal contraction if exposed to rain, or placed upon wet ground.

The main principle for guidance in the arrangement of the various departments, is to place them so that the materials may be transported in their various stages, with a minimum amount of haulage and delay. The examples given in the following pages illustrate other points to which we need not allude further.

The wheel foundry of the Pennsylvania Railway Company, at Altoona, is shown in Plate LXXIX. It forms a wing of the main

shops, and is a brick structure with roof trusses of wrought iron; the roof covering is of slate. The main portion of the foundry, which is 138 feet 6 inches long by 71 feet 6 inches wide and 35 feet high, contains the moulding floor. It is lighted by eleven windows, each 21 feet high and 8 feet wide, as well as by a raised skylight, containing sixty sashes. Ventilation is obtained by louvres in the raised sides of the skylight. On one side of this moulding floor are placed the cupola chamber, 29 feet by 40 feet, the engine house, 30 feet by 30 feet, the boiler house, 30 feet by 15 feet, a core room and ovens of the same dimensions. The operations of annealing and finishing the wheels are prepared in a wing of the foundry, 94 feet long and 56 feet wide. The general arrangement is shown in the plan, Fig. 3; and Figs. 1 and 2 show details of construction. The wheel foundry is furnished with 13 hydraulic cranes, arranged as shown in the plan. The ordinary working pressure for these cranes is 450 lbs. per square inch. Each crane is free to swing entirely round, and controls a circle 13 feet in diameter. They are unsupported at the top, but are well secured to masonry foundations. The jib does not rise and fall, but carries at the end a sheave, over which a wire rope passes and is brought back to the centre of the crane, where it is attached to the piston of the hydraulic cylinder, the travel of which raises or lowers the weights to be moved. The circle of 13 feet diameter, which forms the sweep of the crane, is sufficiently large to give space for fifteen moulding flasks for wheels 33 inches in diameter, which is the largest size used by the Pennsylvania Railway Company. The exact position of each mould around the circle is marked by an iron ring, that forms a level seat for the flask, so that little time is lost in arranging the flasks in their places, and in the proper position for pouring.

We may here mention that the foundry floor is laid with cast-iron plates, provided with narrow-gauge tram grooves, in which two-wheeled trucks are run, transporting the flasks to their respective places.

In the foundry, and immediately beneath the cupolas A, Figs. 1 and 3, is placed a large ladle B, holding about 20,000 lbs., and mounted on trunnions. This ladle is operated by hydraulic power, and is completely under the control of the workman.

Troughs C C from the tapping holes of the cupolas conduct the melted metal into it. It was found advisable to employ a ladle of so large a capacity, because by doing so, a more complete mixture of the different irons is effected, than would be the case if a smaller vessel were employed.

There are two Mackenzie cupolas A A belonging to this department. They are rectangular in section, measuring 7 feet 6 inches by 3 feet 6 inches at the boshes, and 8 feet 6 inches by 4 feet 6 inches at the largest part; the distance from the tuyeres to the charging level is 9 feet 6 inches. These tuyeres form a continuous opening 1½ inch wide, and extend round the cupola, at a height of 8 inches above the floor, when the latter is ready for charging. No flux is employed in melting the charges, and no provision is made for tapping the slag. The average quantity of metal that can be run from each of these cupolas, before the tuyeres become so clogged as to impair the working, is 65,000 lbs. It is true that a larger quantity than this can be run off in a single heat, but it is found that so large a charge does not produce metal of a quality sufficiently good to fulfil the requirements for cast wheels.

In one corner of the cupola chamber is a small furnace having a capacity of 2000 lbs. This is used entirely for experimental purposes, for melting sample irons, and for trying the results of different mixtures, a very necessary process in wheel castings, where marked differences exist in pig irons of the same brands.

The charging stage of the cupola is placed 15 feet 6 inches above the floor level, and is formed of iron plates. The charges are raised to the stage by an hydraulic lift. The charging room is 14 feet high, of the same size as the cupola house, and it is well lighted from above.

The core ovens are placed at the end of the core room, between the latter and the foundry, and they are so arranged that the cores can be placed in the ovens from the core room, and taken out direct into the foundry, so that the handling of the cores is reduced as far as possible. The annealing room D, Figs. 2 and 3, contains 44 pits E E, arranged in one wing of the building. They are disposed in two concentric circles, the outer ring containing 24 and the inner 20 pits. In the centre is placed a hydraulic crane, arranged like those in the foundry, and made to revolve also by

hydraulic power. The pits are cylindrical, and are made of sheet iron lined with firebrick. Outside they are surrounded with a bed of dry sand. Each pit has a capacity of twenty wheels.

Adjoining the annealing chamber is the cleaning and inspecting shop G, where the wheels are stripped of sand that may adhere to them, the cores are broken out, and the wheels are tested by being struck with a hammer. The floor of the room is above the ground level, being raised to the average height of the freight-car platforms for convenience of loading. The cleaning room is paved with oak blocks laid with the grain on end. At one end of this department is an hydraulic drop weighing 1200 lbs., and having a fall of 13 feet. With this, wheels that have failed to pass the test, or which have been worn out in service, are broken up prior to being remelted in the cupola.

A tramway, 2-foot gauge, is laid down throughout the foundry and yards, for convenience of shifting materials.

The operations are carried on in a mode almost identical with that practised in the works described at p. 276.

The foundry of Messrs. Howard, the eminent agricultural implement makers of Bedford, is shown on Plate LXXX. The main building is 258 feet long by 235 feet wide. The roof is of wood and iron, the principals having timber rafters trussed with iron. The whole is covered with white pantiles, machine made, and glass skylight tiles. A portion of the building is divided from the foundry proper by a wall, as shown in the plan and transverse section. The space thus set apart is occupied by the sand stove, into which the sand is shot from the railway trucks through openings, the shutters of which flap down on the truck side, the two core-drying stoves, the cupola room, the engine room, the template store, a pattern room, and a boiler house. Over these run stores and the pattern maker's shop.

The arrangements for melting the iron first claim our attention. There are four cupolas, two of which stand at each side of the entrance gate, as shown in Fig. 2. The upper floor is intercepted to give room for the cupolas, the space being crossed by a light iron staging, used to supply coke and iron, which are raised to the level of the charging floor by two small waterhoists, precisely similar in principle to those used in connection with blast furnaces. Each consists of four columns acting as guides, between which rise and

fall two barrow stages, beneath each of which is a tank, filled, when necessary, from a cistern or tank overhead. The descent of a stage follows on the filling of its tank with water, and in descending it draws up its fellow, by a chain passing over a pulley, the rapidity of descent being controlled by a simple brake. The water is discharged at the bottom, and drains away, to be again pumped up. The distance from the ground to the charging hole is about 15 feet. The cupolas are constructed on Ireland's system. Two of the furnaces will melt between them 25 to 30 tons per day. The metal melted for general casting consists for the most part of about two-thirds pig, four sorts, and one-third scrap. For ploughshares, which are chilled, the iron used is very various and of the highest quality; none other will take the requisite chill and yet be sufficiently strong. The entire cupola work is done by piece work, one man taking the breaking, melting, and serving out at a fixed price per ton. The cupolas are supplied with air by a fan. This fan is fixed overhead, near the pattern shop. It runs at 3500 revolutions per minute, and is almost noiseless. The bearings of the shaft are of great length, and cast iron.

The iron is served out on large ladles, carried on trucks, running on rails laid to a 2-feet gauge, traversing the entire foundry in every required direction, the crossings being fitted with little turntables. The rule is, no moulder is to move from his place for metal. The rails are laid on cast-iron sleepers. The fan, hoist pumps, and other machines, are driven by a double-cylinder horizontal engine, running at a high speed.

A great deal of the moulding is done with moulding machines. The pattern stands up over a flat cast-iron table, a flask is put on the table, parting sand sprinkled over the pattern, and the flask rammed up with moulding sand; a handle is then turned under the table, and a peculiar screw arrangement is put in action, by which the pattern is drawn down from the flask, which is then ready to take its place above or below a similar flask, in which the other half of the article to be cast has been similarly moulded, the cores, if any, being first put in. These cores are all made by special hands; no moulder ever makes a core. The stoves are very complete; one being heated from the waste gases from the boiler on their way to the chimney, the other by a coke fire in the floor.

Plates LXXXI. and LXXXII. are of a large foundry in the north of England, which was specially arranged for heavy marine engineering work.

The pattern makers' shop and stores is about 48 feet by 35 feet, built of brick in three stories, the flooring being supported by iron columns; gates and loading doors being provided to the ground and first floors. Fixed wood racks are provided in each for the patterns, and the whole is covered by a hip slated roof.

The main foundry is a lofty building, about 140 feet long by 71 feet wide, built in two bays upon brick end walls, which rise some 14 feet above ground, the remainder of the structure being timber framed, and glazed and covered by a slated hip louvre roof; massive timber-framed gauntries are arranged in each bay, giving a clear lifting height of 21 feet to the under side of the crane barrel, one of the gauntries being continued into the outer yard for a distance of 100 feet beyond the building. The circular moulding pit is of brick, and is 18 feet in diameter; it was made specially for casting large screw propellers.

There is a smaller foundry, built entirely of brick; this is 93 feet by 34 feet, and is covered by a slated timber hip roof. It is also provided with a gauntry for overhead travelling cranes, and has fixed benches, the smaller mouldings being done here. The spacious core shop and drying stoves are all fitted with well-made iron sliding doors, and the latter with furnaces. The premises throughout are fitted with gas and water piping. There is a siding from the main line delivering goods into the yard, and removing them from a timber loading stage, beneath which the stores for coal, coke, and sand are arranged.

It is difficult to lay down general rules on a subject so much open to the modifications of circumstances and fluctuations of prices as the cost of moulding and casting.

Moulding of the common articles of commerce, and machinery in iron is generally paid for at a price per ton. Dry-sand moulding is paid higher than moulding in green sand, and loam-moulding higher than either of them. The moulding of brass, bronze, or other metals, for monuments of art, is of such variety, and so different are the expenses, that no standard price can be assigned to it. The expenses incurred in melting metal are not very great—

the loss in the metal which is melted is greater than the labour and fuel in melting it. In the cupola, 25 per cent. of fuel is consumed in melting iron, including all the fuel used in warming the furnace, the drying stoves, and other incidental uses of fuel. Besides fuel, there are two labourers at the cupola, one smelter, and one filler. The reverberatory takes from 75 to 100 lbs. of fuel to each 100 lbs. of iron, including the heating of the furnace. Exclusive of this heating, the reverberatory will take but 50 lbs. of fuel. One workman can do the work at the reverberatory, but there are generally two. The melting of iron in the crucible is the most expensive: it consumes from 50 to 200 lbs. of coal to 100 lbs. of iron. The greatest expenses are, however, in the crucibles: a good crucible, well managed, will not generally last more than twelve heats, and if each heat is 50 lbs., it will melt 600 lbs. of iron.

The loss in iron is invariably from 5 to 6 per cent. in every case of the different forms of melting; the reverberatory furnace consuming most iron. Each casting always requires more metal than it will finally contain; this surplus iron, consisting of gates, channels, and false seams, increases the above loss; and as small castings make more scrap iron than large ones, it is obvious that the actual loss will be larger on small casts than on large ones. Machine castings make, on an average, 33 per cent. of refuse, or scrap, in a well-conducted foundry; commercial articles 25 per cent., and large castings less; very small articles frequently make more scrap than ware. The remelting of these scraps costs fuel, and causes a waste of metal, which increases the expense of melting.

Other metals than iron are generally less expensive in melting, being more fusible; and, as far as copper is concerned, there is but little waste if the copper is pure. Bronze will waste a little.

In the general management of a foundry nothing is of more importance to its proprietor than an intelligent system of book-keeping, which, without being needlessly minute in detail, still may enable him to arrive with tolerable accuracy at the cost in materials, labour, and interest on plant, of every important piece of work performed on the premises. This system enables a founder to send in a tender for any special work with ease, rapidity, and almost perfect safety, and is also useful as a check against waste of time and materials by the men.

When the metals in use are costly, such as copper, tin, &c., it is of the utmost importance to guard against waste, and other less excusable sources of loss.

The storekeeper should be provided with books, in which he should be required to enter all the goods received into store, and he should also be empowered to weigh and examine these goods at the period of delivery and to see that they, are correctly described on the invoice sent with them.

It should be his duty to dispose of these stores in such a manner that they can be easily and quickly got at, and every convenience should be allowed him for this purpose, a good weighing machine being especially provided. Unless attention is paid to these points, the storekeeper's door will become the lounging-place of lazy workmen, with the excuse of being kept waiting for metal or stores.

When the storekeeper delivers out metal, or other stock, he should enter the same in a book kept for the purpose, giving the date and quantity issued, and to whom. On the opposite side of the book he should enter the weight of metal returned in the shape of finished castings, with a column for loss in working.

In some instances it will be found possible thus to arrive at the actual metal issued and returned for a particular casting, but such a degree of accuracy cannot often be attained except in the case of very large castings, as some of the metal is generally left over, or used for some other work.

But at certain definite periods, when these books are to be balanced, the general results, as to goods received into store, goods issued by storekeeper, and goods now in stock, should agree; as well as goods issued by storekeeper, and castings produced with the loss in working, which should also agree approximately.

The proportion of different metals used in the castings should also be recorded.

In addition to the stores above mentioned, there are many other items which are not so easily apportioned, or checked, such as timber for the pattern makers, sands, loam, blacking, coal, coke, and similar materials. Care is necessary to prevent these articles being used wastefully, and at the time for balancing the books the cost of these materials must be divided amongst the several items.

CHAPTER XXIX.

ALLOYS.

All alloys, without exception, are far more fusible than the superior metal of which they are composed, as the most refractory metals are easily fused, when alloyed with one or more of the softer metals. Thus platinum, which is scarcely fusible at all, readily combines with any of the inferior metals, zinc, arsenic, tin, and some others. Again, several of the easily fusible alloys melt below the boiling point of water, which is less than half the melting heat of tin, their most fusible ingredient.

The melting and mixing of the several metals, is a point which is far from being reduced to anything like a system in many brass-founding establishments, and practical men are often at a loss as to the proper means for securing a definite and uniform alloy. As a general rule, it is necessary to melt the less fusible metal first, and to add the more fusible afterwards. Founders generally are of opinion, that if the metal of the first melting is run out into a bar, and then remelted, a more complete incorporation is obtained. Where a great difference exists in the specific gravity of the component metals, it is necessary to observe certain fixed rules, in order to obtain a perfectly homogeneous mixture; each metal tends to assume its own particular level in the liquid compound, according to its density; therefore, if the casting is of considerable size, and requires a long time to cool, a partial separation will often take place, the lightest rising towards the surface. In casting large pieces, composed of copper alloys, the lower portion of the casting is apt to contain too much copper, whilst a corresponding excess of tin is found near the upper extremity. To remedy this objection, requires a dexterous manipulation of the liquid metal, previous to casting, so that at the instant of pouring, the alloy may be as nearly homogeneous as possible.

The use of the compound termed *temper*, 16 parts copper to 32 tin, is to assist in the mixing of metals of different qualities.

In the composition of pewter, the minute quantity of copper required would, perhaps, never combine properly with the tin; but if, instead of adding the two metals in the requisite proportions at first, the copper is first melted alone with two or three times its weight of tin, so as to form *temper*, the latter may be added in the requisite quantity to the tin or pewter, and a complete combination is effected. In alloys of zinc, this metal is extremely liable to waste, from its oxidizable and volatile nature; to avoid this, a number of schemes have been adopted, with various degrees of success.

The following table gives the proportions of the more common commercial alloys; while the detailed receipts are of mixtures stated by various authorities to have been used with success.

TABLE XXII.—COMMERCIAL ALLOYS.

	Tin.	Copper.	Zinc.	Antimony.	Lead.	Bismuth.
Brass, engine bearings	13	112	¼	..	..	..
Tough brass, engine work ..	15	100	15	..	..	..
„ for heavy bearings	25	160	5	..	..	..
Yellow brass for turning	..	2	1	..	..	..
Flanges to stand brazing	..	32	1	..	1	..
Bell metal	5	16	..	..	..	..
Babbitt's metal	10	1	..	1	..	..
Brass, for locomotive bearings	7	64	1	..	..	..
„ for straps and glands ..	16	130	1	..	..	..
Muntz's sheathing	..	6	4	..	..	..
Metal to expand in cooling ..	..	..	..	2	9	1
Pewter	100	..	..	17	..	..
Spelter..	..	1	1	..	..	..
Statuary bronze	2	90	5	..	2	..
Type metal from	..	..	..	1	3	..
„ to	..	..	..	1	7	..
Plumbers' sealed solder	1	..	..	..	2	..
„ fine „	2	..	..	..	1	..

TABLE XXIII.—SOLDERS AND THEIR MELTING POINTS.

No.	Tin.	Lead.	Deg. Fahr.	No.	Tin.	Lead.	Bismuth.	Deg. Fahr.
1	1	25	558	10	4	1	0	365
2	1	10	541	11	5	1	0	378
3	1	5	511	12	6	1	0	381
4	1	3	482	13	4	4	1	320
5	1	2	441	14	3	3	1	310
6	1	1	370	15	2	2	1	392
7	1½	1	334	16	1	1	1	354
8	2	1	340	17	2	1	2	336
9	3	1	356	18	3	5	8	202

By the addition of 3 parts of mercury to No. 18 of the Table XXIII. it melts at 122° F.

Tin and copper are liable to separation during the cooling; this can be partly prevented by repeatedly turning and shifting the mould which contains the fluid alloy, until it has set.

To prevent airholes in copper castings, they should be moulded in green sand moulds, using as a flux 1½ lbs. of zinc to every 100 lbs. of copper. Pure copper will not cast without honey-combing.

Copper and lead unite only to a certain extent.

In ordinary pot metal, 3 lead to 8 of copper, the lead may be retained, provided the object to be cast is not too thick.

When the cast is heavy, or much lead is used, it is pressed out by the copper and exudes in cooling.

Two of copper to 1 of lead, separates lead in cooling, the lead oozes through the copper; whilst any excess of copper beyond 8 of copper to 1 of lead renders the alloy very brittle; consequently the range is limited between 2 to 1 and 8 to 1. These alloys are all brittle when heated.

Copper and silver in equal parts with 2 per cent. of arsenic form an alloy similar to silver, with the exception of being a little harder, although of almost equal tenacity and malleability.

Antimony imparts a beautiful red colour to copper, varying from a rose red where much antimony is added, to a crimson or violet tinge with smaller quantities of antimony.

Yellow Brass.—30 parts of zinc and 70 of copper in small pieces.

Yellow Brass for turning.—Copper 20 lbs., zinc 10 lbs., lead from 1 to 5 oz. Put in the lead last before pouring off.

Red Brass for turning.—Copper 24 lbs., zinc 5 lbs., lead 8 oz. Put in the lead last before pouring off. Or copper 32 lbs., zinc 10 lbs., lead 1 lb.

Red Brass to turn freely.—Copper 160 lbs., zinc 50 lbs., lead 10 lbs., antimony 44 ozs.

Best Red Brass for fine Castings.—Copper 24 lbs., zinc 5 lbs., bismuth 1 oz. Put in the bismuth last before pouring off.

Rolled Brass.—Copper 32, zinc 10, tin 1·5.

Common Brass for Castings.—Copper 20, zinc 1·25, tin 2·5.

Hard Brass for Casting.—Copper 25, zinc 2, tin 4·5.

Bell Metal.—Fine, 71 copper, 26 tin, 2 zinc, 1 iron. For large bells: copper 100 lbs., tin 20 to 25 lbs. For small bells: copper 3 lbs., tin 1 lb.

For Bells of Clocks.—Copper 72·00 parts, tin 26·56 parts, iron 1·44 parts.

For Journal Boxes.—Copper 24 lbs., tin 24 lbs., antimony 8 lbs. Melt the copper first, then add the tin, and lastly the antimony. It should first be run into ingots, then melted, and cast in the required form. 10 lbs. copper, 1 lb. tin, 10 oz. zinc is another mixture.

Queen's Metal.—100 lbs. tin, 8 of regulus of antimony, 1 of bismuth, 4 of copper.

Chinese Silver.—65·24 parts copper, 19·52 zinc, 13 nickel, 2·5 silver, and 0·12 cobalt of iron.

Hard White Metal.—3 lbs. grain copper, 90 lbs. tin, 70 lbs. antimony.

Metal for taking Impressions.—Lead 3 lbs., tin 2 lbs., bismuth 5 lbs.

Gun Metal.—80 to 83 parts copper, 20 to 17 parts tin.

Rivet Metal.—Copper 32 oz., tin 2 oz., zinc 1 oz.

Rivet Metal for Hose, Belting, &c.—Copper 64 lbs., tin 1 lb.

Bullet Metal.—98 lead, 2 arsenic.

Aluminum Bronze.—100 parts copper, 10 aluminum by weight, form a durable alloy, which may be forged and worked in the same manner as copper; it is of a pale golden colour.

Useful Alloy for Bearings.—10 antimony, 5 copper, 85 tin.

For Cymbals and Gongs.—100 parts of copper, 25 of tin. It is stated that to give this alloy a high degree of sonorous power, the piece should be ignited after it is cast, and then be immediately plunged into cold water; but these directions, like a good many others which accompany receipts for alloys, are unfortunately very vague.

For Tam-Tams, or Gongs.—(1.) 80 parts copper, 20 of tin; hammer it out, with frequent annealing. (2.) 78 parts of copper, 22 of tin, rolled out.

Bath Metal.—32 brass, and 9 zinc.

Cock Metal.—20 lbs. copper, 8 lbs. lead, 1 oz. litharge, 3 oz. antimony.

TABLE XXIV.—WHITE METALS.

Tin.	Lead.	Copper.	Bismuth.	Antimony.	Brass.	Iron.	Zinc.	Mercury.	Alloys.
89	..	2	2	7	..	..	..	..	Plate pewter.
75	9	..	8	8	..	..	..	..	Queen's metal.
89	..	2	..	6	2	1	..	..	Britannia metal.
4	1	..	..	..	..	..	..	..	Pewter.
80	..	..	..	20	..	..	..	..	Music metal.
50	..	..	..	..	..	..	50	..	Silver leaf.
90	10	..	..	..	..	..	..	..	Organ pipes.
100	..	2	2	8	..	..	..	..	Best plate pewter.
29	19	..	..	..	..	..	..	..	Reflector metal.

The last two alloys are used for coating the inside of glass globes, and many other similar toys. A little of the metal is poured into the globe or other vessel, which being turned about receives a thin film of a brilliant silvery appearance, the excess of metal being poured back into the ladle.

Tin foil should be of pure tin, but it is nearly always alloyed with lead, or with lead and zinc. It may be prepared either by hammering or rolling, but is more generally cast upon an inclined framework covered with canvas.

Expansive Metal.—9 lead, 2 antimony, 1 bismuth. This alloy expands on cooling, and is used for filling small holes or defects in castings.

Gold Coin of Great Britain.—11 pure gold, 1 copper.

Mannheim Gold.—3 copper, 1 zinc, with a little tin.

British Standard Measures, Metal for.—576 copper, 59 tin, and 48 brass.

Hard Alloy, resembling Silver.—1 iron, 1 cobalt, and 1 nickel, fused together.

Silver Coin of Great Britain.—11·1 pure silver, ·9 copper.

Lining Metal for Boxes of Railway Cars.—Tin 24 lbs., copper 4 lbs., antimony 8 lbs.; mix these, and afterwards add and mix 72 lbs. tin.

Bronze Metal.—(1.) copper 7 lbs., zinc 3 lbs., tin 2 lbs. (2.) Copper 1 lb., zinc 12 lbs., tin 8 lbs.

Bronze for Gilding.—This should be fusible at a low temperature, compact, and close grained. 82·25 copper, 17·50 zinc, and ·25 tin, is said to take gilt well.

Blanched Copper.—Fuse 8 ozs. of copper and ½ oz. of neutral

arsenical salt, with a flux made of calcined borax, charcoal dust, and powdered glass.

White Metal.—Tin 82, lead 18, antimony 5, zinc 1, and copper 4 parts.

Statuary Metal.—(1.) 91·4 parts copper, 5·53 zinc, 1·7 tin, 1·37 lead. (2.) Copper 80 parts, tin 20.

For Medals.—(1.) 50 parts copper, 4 of zinc. (2.) Copper 92 parts, tin 8 parts, with a small quantity of brass.

Or-molu.—The or-molu of the brass-founder, which is an imitation of red gold, is extensively used in ornamenting ironwork, as well as in many other branches of artistic trade. It is composed of more copper and less zinc than ordinary brass; it is readily cleaned by acid, and can be easily burnished. To make it more brilliant it can be brightened up, after "dipping," by means of scratch-brush. To protect it from tarnish it should be lacquered.

For Tinning.—Malleable iron 1 lb.; heat to whiteness, add 5 oz. regulus of antimony, and Molucca tin 24 lbs.

Cold Tinning.—Mix tin and mercury until soft and friable; clean the article with spirits of salt, and whilst moist rub on the above amalgam, and after the metal is tinned evaporate the mercury by heat. This *receipt must not* be used for any *culinary* vessel.

Cold Silvering.—1 chloride of silver, 3 pearlash, 1½ common salt, 1 whitening. Clean the metal with soft leather or cork, moisten the metal with clean water, and rub on the mixture. After the metal is silvered, wash it in slightly alkaline hot water.

Speculum Metals.—Equal parts of tin and copper form a white metal as hard as steel. Less tin, with a small quantity of arsenic added to the alloy, form a hard white metal, having a brilliant lustre. 2 lbs. copper, 1 lb. tin, 1 oz. arsenic, is a good mixture.

32 parts copper, 16·5 tin, 4 brass, and 1·25 arsenic, gives a hard, white, and brilliant metal.

Pipe Metal for Organs.—Melt equal parts of tin and lead. This alloy is cast, instead of being rolled, in the desired form of sheets, in order to obtain a crystallized metal, which produces a finer tone.

The sheets are formed by casting the metal on a horizontal

table, the thickness being regulated by the height of a bridge at one end, over which the superfluous metal flows off. The sheets thus obtained are planed with a carpenter's plane, bent up, and soldered.

German Silver.—First quality for casting: Copper 50 lbs., zinc 25 lbs., nickel 25 lbs.

Second quality for casting: Copper 50 lbs., zinc 20 lbs., nickel, best pulverized, 10 lbs.

German Silver for Rolling.—Copper 60 lbs., zinc 2 lbs., nickel 25 lbs.; used for table ware.

German Silver for Bells and other Castings.—Copper 60 lbs., zinc 20 lbs., nickel 20 lbs., lead 3 lbs., iron, that of tin plate being best, 2 lbs.

It is difficult to combine a definite proportion of zinc with the compound of nickel and copper previously prepared. In fusing the three metals together there is always a loss of zinc by volatilization, which may be lessened by placing the zinc beneath the copper in the crucible. The best method is to mix the copper and nickel, both in grains, first; place this mixture in the crucible; when melted, add the zinc and a piece of borax the size of a walnut. The zinc will gradually dissolve in the fluid copper, and the heat may be raised as the fluidity increases.

In this instance, as in all others of forming alloys, it is profitable to mix the oxides of the various metals together, and reduce them under the protection of a suitable flux. The metal nickel can be produced only from pure oxide of nickel, and as purity of the alloy is essential to good quality, the common commercial zinc is *not* sufficiently pure for some purposes. Copper cannot well be used in the form of oxide, but grain copper or wire scraps will serve equally well.

Pinchbeck.—Copper 5 lbs., zinc 1 lb.

Tombac.—Copper 16 lbs., tin 1 lb., zinc 1 lb.

Red Tombac.—Copper 10 lbs., zinc 1 lb.

Frick's German Silver.—53·39 parts copper, 17·4 nickel, 13 zinc.

Hardening for Britannia Metal.—To be mixed separately from the other ingredients. Copper 2 lbs., tin 1 lb.

Good Britannia Metal.—Tin 150 lbs., copper 3 lbs., antimony 10 lbs.

Britannia Metal, Second Quality.—Tin 140 lbs., copper 3 lbs., antimony 9 lbs.

Britannia Metal for Casting.—Tin 210 lbs., copper 4 lbs., antimony 12 lbs.

Britannia Metal for Spinning.—Tin 100 lbs., hardening 4 lbs., antimony 4 lbs.

Britannia Metal for Registers.—Tin 100 lbs., hardening 8 lbs., antimony 8 lbs.

Best Britannia for Spouts.—Tin 140 lbs., copper 3 lbs., antimony 6 lbs.

Best Britannia for Spoons.—Tin 100 lbs., hardening 5 lbs., antimony 10 lbs.

Best Britannia for Handles.—Tin 140 lbs., copper 2 lbs., antimony 5 lbs.

Best Britannia for Lamps, &c.—Tin 300 lbs., copper 4 lbs., antimony 15 lbs.

Britannia for Casting.—Tin 100 lbs., hardening 5 lbs., antimony 5 lbs.

Britannia Metal.—4 brass, 4 tin; when fused, add 4 bismuth and 4 antimony; this composition is added at discretion to the melted tin.

Casting Brass Nuts on Screws.—Polish the screw, make a mould on it, with a gate or runner at the end when mould is horizontal, 1 inch in diameter, 5 inches high, scoop out the top 3 inches diameter bevelled down to 1 inch; second, make the gate or runner on the top of screw ½ inch diameter, same height as the other. Take a pricker and prick from the top of the mould to the pattern nut about a dozen holes, after which draw diamonds with the wire from these holes to the sides of the mould on the top. Now part the mould, draw the nut and screw, cut the gates, making the one at the end of nut same as the down one, an inch in diameter; take the screw, smoke it over a gas flame, turning it round, pouring a little oil on it; continue heating till the oil begins to boil; at this stage take a little of the dry parting-sand, which is used to part the mould; sprinkle this all round on the top of oil—heat now as

before to dull red, and proceed as before. Remelt the metal, take 3 lbs. of old waste handles, free from iron; add to this 9 lbs. of copper; melt both, and when ready for casting add ½ lb. of zinc or spelter; allow it to remain in the fire ten minutes; take it out, add ½ lb. of block tin and ¼ lb. of lead; stir the whole well up; the screw is now red and in the mould; rush the metal in quickly at the gate 1 inch diameter; be sure the metal is hot and it will rise at the other gate to the top of the mould. Be careful at this stage. To take the nut off do not heat it; dress it as before; hammer it cold, heat it—now hold the screw upright, pour on oil at the top of the nut, allow it to cool, catch nut in vice, apply a lever to the square at end of screw, and turn it round.

Babbitt's Attrition Metal.—Preparing and fitting: melt separately 4 lbs. of copper, 12 lbs. best quality Banca tin, 8 lbs. regulus of antimony, and 12 lbs. more of tin while the composition is in a melted state. Pour the antimony into the tin, then mix with the copper away from the fire in a separate pot.

In melting the composition, it is better to keep a small quantity of powdered charcoal on the surface of the metal.

The above composition is called "hardening." For lining the boxes take 1 lb. of hardening and melt it with 2 lbs. of Banca tin, which produces the lining metal for use. Thus the proportions for lining metal are, 4 lbs. of copper, 8 lbs. of regulus of antimony, and 96 lbs. of Banca tin.

The article to be lined, having been cast with a recess for the lining, is to be nicely fitted to a "former," which is made of the same shape as the bearing. Drill a hole in the article for the reception of the metal, say ½ or ¾ inch diameter, according to the size of it. Coat over the part not to be tinned with a clay wash, wet the part to be tinned with alcohol, and sprinkle on it powdered sal-ammoniac; heat it till a fume arises from the sal-ammoniac, and then immerse in melted Banca tin, taking care not to heat it so that it will oxidize. After the article is tinned, if it should have a dark colour, sprinkle a little sal-ammoniac on it, which will make it a bright silver colour. Cool it gradually in water, then take the "former," to which the article has been fitted, and coat it over with a thin clay wash, and warm it so that it will be perfectly dry; heat the article until the tin

begins to melt, lay it on the "former," and pour in the metal, which should not be so hot as to oxidize, through the drilled hole, giving it a head, so that as it shrinks it will fill up. After it has sufficiently cooled remove the "former."

A shorter method may be adopted when the work is light enough to handle quickly; namely, when the article is prepared for tinning, it may be immersed in the lining metal instead of the tin, brushed lightly in order to remove the sal-ammoniac from the surface, placed immediately on the "former" and lined at the same heating.

Stereotype Metal.—Tin 1, antimony 1, lead 4 parts.

In using stereotype metal, brush the type with plumbago or a small quantity of oil; then place in a frame, and take a cast with plaster of Paris. The cast must be dried in a very hot oven, placed face downwards upon a flat plate of iron; this plate is laid in a tray or pan of iron, having a lid securely fastened, and furnished with a hole at each corner. Dip the tray in the fluid metal, which will flow in at the four corners. When the tray is removed, dip the bottom only in water, and as the metal contracts in cooling, pour in melted metal at the corners, so as to keep up the fluid pressure and obtain a good solid cast.

When cool, open the tray, remove the cake of plaster and metal, and beat the edges with a wooden mallet to remove superfluous metal. Plane the edges square, turn the back flat in a lathe to the required thickness, and remove any defects. If any of the letters are damaged, cut them out, and replace them with separate type soldered carefully in place. Finally, fix upon hard wood to the required height.

Casting Stereo Plates by the Paper Process.—Lay a sheet of tissue paper upon a perfectly flat surface, and paste a piece of soft printing paper on to the tissue paper, pressing them very flat and even. Oil the form of type, lay the paper on it, and cover with a damp rag; beat the paper evenly into the type with a stiff brush, then paste on it a piece of blotting paper, and repeat the beating-in process, after which several other layers of soft, tenacious paper must be pasted on and beaten-in in the same manner; back up the paper with a piece of cartridge paper. The whole must then be dried at a moderate heat under a slight pressure. When quite

dry, brush over the face of the paper mould with plumbago or French chalk. When this is done it is ready for the matrix. This is a box of the size required for the work, the interior of which is type-high. This is called the gauge, and lifts out to insert the paper mould, and is regulated by hand to the size of the plate required. This being placed inside, the lid is shut down and screwed tight, with the end or mouthpiece left open. The metal is poured in at the orifice, and as it is mounted to swing, the box is moved about so as to well throw down the metal and make a solid cast. Then water is dashed on the box, the screw-bar unshackled, the lid lifted, the plate taken off, and the paper mould is ready for use for another casting.

Another Stereotype process.—The stereotyper first dries the form of types upon an iron steam table. The form is then partially unlocked, and a hand-brush is rubbed over the surface of the types, cleansing them preparatory to placing over the entire form a sheet or sheets of thin bank-note paper, of the finest quality, previously wetted to insure the required pliability. This paper being evenly laid over the types, the workman takes a long-handled brush, made of short, stiff bristles, with which he beats the wet paper evenly, forcing it into all depressions of the types, taking care not to break the paper. The work finished, a dampened sheet of thicker, more ordinary paper is placed over the first. This is also brush-hammered down upon the types, and followed by another sheet of paper, thinly coated with a preparation of whiting and starch. Again the brush is used to beat this home, after which a brown paper backing is put on, and then the form of types, covered by the before-mentioned sheets of paper, is trundled to another steam table, where it is slid under a powerful screw press, several blankets folded over it, and all firmly held down until the paper matrix is dry-hardened, or "cooked," as the workmen express it. The papering process occupies three or four minutes, the cooking about twice as many. The matrix is now peeled off from the form, and prepared for casting by sifting it with finely powdered borax, which with a soft brush is thoroughly rubbed into the sunken surface left by the types. The surplus borax having been removed, the matrix, which now resembles hard but pliable pasteboard, is ready for the casting box, which is made of iron, either straight or curved, to suit the

press-bed. Handle irons hold the matrix in its proper place, at the exact distance, about half an inch, necessary for the thickness of the stereotype plate, which is made by pouring a quantity of hot type metal into an open end of the casting box. This metal, dropping between one surface of the casting box and the sunken surface of the matrix, fills up the latter without burning it. A few moments are allowed for cooling, and then the matrix is stripped from the warm plate, which is subsequently prepared for the press by trimming down all thick lines, or chiselling away any superfluous metal, paring off the edges, filing, and otherwise treating the stereotype after the usual manner. Circular saws driven by steam power, and hand cutting machinery of various kinds, are used in finishing, the whole operation of stereotyping occupying from fifteen to twenty minutes. A second plate may be obtained from the original matrix in about two minutes, and almost any number of castings can be taken by careful workmen. In some offices only one mould is taken, this being used for casting the number of plates required for several presses. The stereotype, being an exact reproduction, in solid plate form, of the million or more types originally put together by the compositors, is fastened upon the Hoe, Bullock, or any other printing press, and used in place of the types.

Type Metal.—9 parts lead to 1 of antimony forms common type metal; 7 lead to 1 antimony is used for large and soft type; 6 lead, 1 antimony, for large type; 5 lead and 1 antimony for middle type, 4 lead, 1 antimony, for small type; and 3 lead to 1 antimony for the smallest and hardest kinds of type.

French Type Metal consists of 2 lead, 1 antimony, and 1 copper.

Common Type Metal is 80 lead and 20 antimony; a more fusible stereotype metal is 77 lead, 15 antimony, and 8 bismuth. If much tin is used it renders the metal rather soft, but fusible and fit for fine impressions. A superior alloy is said to consist of 9 lead, 2 antimony, and 1 bismuth. To alloy lead with these metals, the lead is first melted, and the other metals added to the fluid lead.

CHAPTER XXIX.

A COLLECTION OF USEFUL TABLES AND NOTES.

Table XXV.—Weight of Round and Square Copper Rods in Lbs.

Size of Rod.	Weight per Lineal Foot. Round.	Weight per Lineal Foot. Square.	Size of Rod.	Weight per Lineal Foot. Round.	Weight per Lineal Foot. Square.	Size of Rod.	Weight per Lineal Foot. Round.	Weight per Lineal Foot. Square.
1/4	0·19	0·24	1 1/8	3·86	4·91	2	12·20	15·53
5/16	0·30	0·38	1 3/16	4·30	5·47	2 1/16	12·97	16·51
3/8	0·43	0·55	1 1/4	4·77	6·06	2 1/8	13·77	17·53
7/16	0·58	0·74	1 5/16	5·25	6·68	2 3/16	14·60	18·58
1/2	0·76	0·97	1 3/8	5·77	7·34	2 1/4	15·44	19·65
9/16	0·96	1·23	1 7/16	6·30	8·02	2 5/16	16·31	20·76
5/8	1·19	1·52	1 1/2	6·86	8·73	2 3/8	17·20	21·90
11/16	1·44	1·83	1 9/16	7·45	9·48	2 7/16	18·12	23·06
3/4	1·72	2·18	1 5/8	8·05	10·25	2 1/2	19·06	24·25
13/16	2·01	2·56	1 11/16	8·69	11·05	2 5/8	21·02	26·75
7/8	2·33	2·97	1 3/4	9·34	11·89	2 3/4	23·07	29·36
15/16	2·68	3·41	1 13/16	10·02	12·75	2 7/8	25·21	32·09
1	3·05	3·88	1 7/8	10·72	13·65	3	27·45	34·94
1 1/16	3·44	4·38	1 15/16	11·45	14·57			

Table XXVI.—Areas of Circles.

Diam.	Area.	Diam.	Area.	Diam.	Area.	Diam.	Area.
in.	sq. in.	in.	sq. in.	in.	sq. in.	in.	sq. in.
1/8	0·012	1 7/8	2·761	5	19·63	16	201·1
3/16	0·028	2	3·142	5 1/4	21·65	17	227·0
1/4	0·049	2 1/8	3·546	5 1/2	23·76	18	254·5
5/16	0·076	2 1/4	3·976	5 3/4	25·97	19	283·5
3/8	0·110	2 3/8	4·430	6	28·27	20	314·2
7/16	0·150	2 1/2	4·904	6 1/2	33·18	21	346·4
1/2	0·196	2 5/8	5·412	7	38·48	22	380·1
9/16	0·249	2 3/4	5·939	7 1/2	44·18	23	415·6
5/8	0·307	2 7/8	6·492	8	50·26	24	452·4
11/16	0·371	3	7·069	8 1/2	56·74	25	490·9
3/4	0·442	3 1/8	7·670	9	63·62	26	530·9
13/16	0·519	3 1/4	8·296	9 1/2	70·88	27	572·6
7/8	0·601	3 3/8	8·946	10	78·54	28	615·7
15/16	0·691	3 1/2	9·621	10 1/2	86·59	29	660·5
1	0·785	3 5/8	10·32	11	95·03	30	706·9
1 1/8	0·994	3 3/4	11·04	11 1/2	103·9	31	754·8
1 1/4	1·227	3 7/8	11·79	12	113·1	32	804·2
1 3/8	1·485	4	12·57	13	132·7	33	855·3
1 1/2	1·767	4 1/4	14·19	14	153·9	34	907·9
1 5/8	2·074	4 1/2	15·90	15	176·7	35	902·1
1 3/4	2·405	4 3/4	17·72				

TABLE XXVII.—COLOURS EXPRESSING HIGH TEMPERATURES.

	Degrees Fahr.
Faint red	960
Dull red	1290
Brilliant red	1470
Cherry red	1650
Bright ditto ditto	1830
Orange	2010
Bright ditto	2190
White heat	2370
Bright ditto ditto	2550

TABLE XXVIII.—PROPERTIES OF THE METALS.

	Chemical Equivalents.		Specific Gravity Water at 60° = 1.	Melting Point. Fahr.	
	Hydrogen = 1.	Oxygen = 100. Hydrogen = 12·5.		degrees	
Gold	98·33	1229·16	19·26	2016	(Rankine 2590°.)
Silver	108·00	1350·00	10·47	1837	(Rankine 1280°.)
Iron	28·00	350·00	7·78	2786	(Rankine says cast iron 3479°.)
Copper	31·66	395·70	8·89	1996	(Rankine 2548°.)
Mercury	100·07	1250·90	13·60	39	
Lead	103·56	1294·50	11·35	612	
Tin	58·82	735·24	7·30	442	(Rankine 426°.)
Antimony	129·03	1612·90	6·70	810	
Bismuth	70·95	886·92	9·80	497	Bismuth 8, lead 5, tin 3, melts in boiling water.
Zinc	32·52	406·59	7·00	773	Very malleable at 212° Fahr.
Arsenic	75·00	935·70	5·88	700	Hardens any metal with which it may be mixed.
Cobalt	29·52	368·99	8·53	2800	Rarely used in metallic state.
Platinum	98·68	1233·50	20·98	..	Can be melted before the oxy-hydrogen blowpipe. Scarce metal, nearly as valuable as gold.
Nickel	29·57	369·68	8·27	2800	German silver—best, 8 copper, 3 nickel, 3½ zinc; common, 8 copper, 2 nickel, 4 zinc.
Palladium	53·27	665·90	11·80	..	Hard, ductile, and malleable.
Rhodium	52·11	651·39	10·65	..	White, and very hard.
Potassium	39·00	487·50	0·865	136	Very inflammable.
Aluminum	13·69	171·17	2·58	..	Very malleable.
Magnesium	12·67	158·35	2·24	..	Hard, but ductile like silver. Volatile at white heat.
Manganese	..	..	8·00	..	
Cadmium	..	..	8·70	..	
Sodium	..	..	0·97	..	
Iodine	..	..	4·94	..	
Phosphorus	..	..	1·77	..	Boils at 550°.
Sulphur	..	..	1·98	228	Boils at 570°.

P.S.—Authorities differ considerably as to the temperature at which most of the metals can be melted, owing no doubt to errors in pyrometers.

Table XXIX.—Specific Heats, Water being 1·0000.

Charcoal	0·2631	Mercury	0·0332
Sulphur	0·1850	Platinum	0·0324
Iron	0·1188	Gold	0·2998
Zinc	0·0955		

Table XXX.—Boiling Temperatures of certain Substances.

	Degrees.		Degrees.
Mercury (about)	600	Arsenic (volatilizes)	356
Linseed oil	640	Naphtha	320
Whale oil	630	Sodium (fuses)	200
Sulphur	570	Alcohol	174
Oil of turpentine (about)	350	Wood spirit	133
Phosphorus	550		

Table XXXI.—Comparative Weights of various Metals.

	Cast Iron being 1.	Dry Deal being 1.	Dry Plane Tree being 1.	Wrought Iron being 1.	Brass being 1.	Copper being 1.
Cast iron	1·	16·8	11·	0·94	0·84	0·80
Steel	1·08	..	..	1·01	..	..
Brass	1·16	19·8	12·7	1·09	1·00	..
Copper	1·21	20·4	13·3	1·15	1·05	..
Lead	1·56	24·	17·1	1·48	1·34	1·27
Tin	..	17·12	11·2	0·94	..	..
Zinc	..	..	..	0·92	..	..

Mill loam, properly dried in core, for every pound of core required:

4·6 lbs. cast iron.
4·8 „ patent white metal.
5·4 „ cast brass.

Table XXXII.—Weight of a Square Foot of various Metals.

Thickness	Wrought Iron.	Copper.	Brass.	Lead.	Cast Iron.	Steel.	Zinc.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
One-sixteenth of an inch	2·5	2·9	2·7	3·7	2·3	2·5	2·3
One-eighth „	5·0	5·8	5·5	7·4	4·7	5·1	4·7
Three-sixteenths „	7·5	8·7	8·2	11·1	7·0	7·7	7·0
One-quarter „	10·0	11·6	10·9	14·8	9·4	10·2	9·4
Five-sixteenths „	12·5	14·5	13·6	18·5	11·7	12·8	11·7
Three-eighths „	15·	17·4	16·3	22·2	14·1	15·3	14·1
Seven-sixteenths „	17·5	20·3	19·0	25·9	16·4	17·9	16·4
One-half „	20·	23·2	21·8	29·6	18·7	20·4	18·7
Five-eighths „	25·	28·9	27·1	37·0	23·4	25·5	23·4
Three-quarters „	30·	34·7	32·5	44·4	28·1	30·6	28·1
Seven-eighths „	35·	40·4	37·9	57·8	32·8	35·7	32·8
One inch	40·	46·2	43·3	59·2	37·5	40·8	37·5

TABLE XXXIII.—PERCENTAGE OF CARBON AND SILICON CONTAINED IN VARIOUS KINDS OF CAST AND WROUGHT IRON AND STEEL.

Description.	Carbon.	Silicon.	Authority.
	per cent.	per cent.	
Spiegeleisen (New Jersey, U.S.)	6·900	0·100	Henry.
" (German)	5·440	0·179	Schafhäutl.
" (Musen)	4·323	0·997	Fresenius.
Löfsta pig iron (Dannemora, Sweden) ..	4·809	0·176	Henry.
Grey pig iron, No. 1 (Tow Law)	2·795	4·414	Riley.
Grey pig iron, No. 1 (Acadian Iron Co.) ..	3·500	4·840	Tookey.
Grey foundry pig iron, No. 1 (Netherton, South Staffordshire)	3·07	1·48	Woolwich Arsenal.
Ditto ditto, No. 2, ditto ..	3·04	1·27	"
Grey forge pig iron ditto ..	3·12	1·16	"
Forge pig iron, ditto ..	3·03	0·83	"
Strong forge pig iron ditto ..	2·81	0·57	"
Grey pig iron (Dowlais)	3·14	2·16	Riley.
Mottled ditto, ditto	2·95	1·96	"
White ditto, ditto	2·84	1·21	"
Mottled pig iron (Wellingborough) ..	2·10	2·11	Woolwich Arsenal.
White pig iron (Blaenavon)	2·31	1·11	Percy.
Refined iron (Bromford, S. Staffordshire)	3·070	0·630	Dick.
Puddled steel, hard (Konigshütte)	1·380	·006	Brauns.
Ditto ditto, mild (South Wales)	·501	·106	Parry.
Cast steel, Wootz	1·34	..	Henry.
" for flat files	1·2	..	A. Willis.
" (Huntsman's) for cutters ..	1·0	..	"
" for chisels	·75	..	"
" Die steel (welding)	·74	..	"
" double shear steel	·7	..	"
" quarry drills	·64	..	"
" masons' tools	·6	..	"
" spades	·32	..	"
" railway tires	32 to 27	..	"
" rails	26 to 24	..	"
" plates for ships	·25	..	Various.
" very mild .. .. .. " (melted on open hearth) ..	·18	..	A. Willis.
Hard bar iron (South Wales)	·410	·080	Schafhäutl.
" " (Kloster, Sweden)	·386	·252	Henry.
" " (Russia)	·340	Trace	"
" " "	·272	·062	"
Boiler plates (Russell's Hall, South Staffordshire)	·190	·144	"
Armour plates (Weardale Iron Co.), too steely	·170	·110	Percy.
Bar iron (Löfsta, Sweden)	·087	·115	Henry.
" (Gysinge, Sweden)	·087	·056	"
" (Osterby, Sweden)	·054	·028	"
Armour plates (Beale & Co.)	·044	·174	Percy.
" (Thames Iron Co.)	·033	·160	"
" (Low Moor)	·016	·122	Tookey.

TABLE XXXIV.—THICKNESS AND WEIGHT OF WIRE.

Birmingham Wire Gauge.	Inches.	Wire. Weight of 100 Lineal Feet. Iron.	Steel.	Brass.	Copper.	Thickness by B. W. G.	Weight of a Square Foot in Lbs. Iron.	Copper.	Brass.
		lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.
0000 =	$\frac{15}{32}$								
000 =	$\frac{7}{16}$								
00 =	$\frac{3}{8}$								
0 =	$\frac{11}{32}$	30·58	30·92	33·43	35·17				
1 =	$\frac{5}{16}$	25·75	26·04	28·15	29·62	1	12·50	14·50	13·75
2		21·34	21·57	23·32	24·54	2	12·0	13·90	13·20
3		18·02	18·22	12·70	20·72	3	11·00	12·75	12·10
4 =	$\frac{1}{4}$	15·11	15·28	16·52	17·38	4	10·00	11·60	11·00
5		12·46	12·59	13·62	14·33	5	8·74	10·10	9·61
6		11·45	11·57	12·51	13·16	6	8·12	9·40	8·93
7 =	$\frac{3}{16}$	9·25	9·35	10·11	10·64	7	7·50	8·70	8·25
8		7·29	7·37	7·97	8·38	8	6·86	7·90	7·54
9		6·60	6·68	7·22	7·59	9	6·24	7·20	6·86
10		4·96	5·02	5·43	5·71	10	5·62	6·50	6·18
11 =	$\frac{1}{8}$	4·18	4·18	4·52	4·75	11	5·00	5·80	5·50
12		3·14	3·18	3·43	3·61	12	4·38	5·08	4·81
13		2·34	2·36	2·55	2·69	13	3·75	4·34	4·12
14		1·69	1·71	1·85	1·95	14	3·12	3·60	3·43
15		1·37	1·39	1·50	1·58	15	2·82	3·27	3·10
16 =	$\frac{1}{16}$	1·05	1·06	1·15	1·21	16	2·50	2·90	2·75
17		·80	·81	·87	·92	17	2·18	2·52	2·40
18		·61	·62	·67	·70	18	1·86	2·15	2·04
19		·47	·47	·51	·54	19	1·70	1·97	1·87
20		·32	·33	·34	·37	20	1·54	1·78	1·69
21						21	1·40	1·62	1·54
22 =	$\frac{1}{32}$					22	1·25	1·45	1·37
23						23	1·12	1·30	1·23
24						24	1·04	1·16	1·10
25						25	0·90	1·04	0·99
26						26	·80	·92	·88
27						27	·72	·83	·79
28						28	·64	·74	·70
29						29	·56	·64	·61
30						30	·50	·58	·55

TABLE XXXV.—QUALITIES OF USEFUL METALS.

Relative Weights.		Strength to resist Torsion.		Tenacity.		Order of Ductility. Wire-drawing.	Laminable.
Lead	148	Cast steel	195	Gold	1110	Gold	Gold
Copper	116	Shear do.	170	Iron	1000	Silver	Silver
Brass	109	Blistered do.	166	Silver	820	Platinum	Copper
Steel	102	English iron	101	Brass	820	Wrought iron	Tin
Bar iron	100	Swedish do.	95	Copper	665	Copper	Platinum
Cast „	95	Cast iron	90	Tin	110	Zinc	Lead
Cast zinc	95	Gun metal	50	Lead	65	Tin	Zinc
		Yellow brass	46			Lead	Wrought iron
		Copper	43			Nickel	Nickel
		Tin	14			Palladium	Palladium
		Lead	10				

TABLE XXXVI.—SHRINKAGE OF CASTINGS.

In locomotive cylinders	= $\frac{1}{16}$ inch in a lineal foot.
In pipes	= $\frac{1}{8}$ " "
Girders, beams, &c.	= $\frac{1}{8}$ in 15 inches.
Engine beams, connecting rods	= $\frac{1}{8}$ in 16 inches.
In large cylinders, say 70 inch diameter, 10 feet stroke, the contraction of diameter	= $\frac{3}{8}$ at top.
Ditto	= $\frac{1}{4}$ at bottom.
Ditto in length	= $\frac{1}{8}$ in 16 inches.
In thin brass	= $\frac{1}{8}$ in 9 inches.
In thick brass	= $\frac{1}{8}$ in 10 inches.
In zinc	= $\frac{5}{16}$ in a foot.
In lead	from $\frac{1}{8}$ to $\frac{5}{16}$ in a foot.
In copper	= $\frac{3}{16}$ in a foot.
In bismuth	= $\frac{5}{32}$ "
In tin	from $\frac{1}{12}$ to $\frac{1}{4}$ "

EASY RULE TO FIND APPROXIMATE WEIGHT OF CASTINGS.

Thickness in $\frac{1}{8}$ inches × width in $\frac{1}{4}$ inches × length in feet = lbs. weight cast iron.

For lead add one-half to the result.
For brass add one-seventh "
For copper add one-fifth "

TABLE XXXVII.—WEIGHT OF TIMBER PER CUBIC FOOT.

	Lbs.		Lbs.
Acacia	44	Lignum vitæ	76
Ash	48	Lime tree	47½
Beech	46	Mahogany, Honduras ..	35
Birch	49½	" Spanish ..	53 to 56
Box	60	Norway spar	36
Cedar	48 to 56	Oak, Adriatic	62
Chestnut	55	" Canadian	55
Cork	15	" Dantzic	47
Deal	43	" English	58
" English	30	Pear tree	41
Elm	35 to 44	Plane tree	40
Fir, Mar Forest	44	Poplar	33 to 24
" New England	35	Pine, pitch	41 to 43
Riga	47	" red	41
Larch	34	" yellow	38
Hawthorn	38	Sycamore	38 to 43
Hazel	54	Teak	47
Holly	48	Willow	24
Hornbeam	47½	Yew	50
Lancewood	64		

TABLE XXXVIII.—WEIGHTS OF USEFUL METALS.

Name of Metal.	Cubic foot.	1 ft. sq. by 1 in. thick.	Bar 1 in. square by 1 ft. long.	Bar 1 in. diam. by 1 ft. long.
	lbs.	lbs.	lbs.	lbs.
Cast iron	450	37·5	3·12	2·45
Wrought iron	475	40·5	3·33	2·61
Steel	490	40·8	3·40	2·67
Copper (cast)	549	45·7	3·81	2·99
Gun metal	510	42·5	3·54	2·78
Brass (yellow)	523	43·6	3·63	2·85
Lead (cast)	710	59·3	4·94	3·88
Zinc (cast)	439	36·6	3·05	2·40

WEIGHT OF LEAD.

22 cwt. = 1 fodder of lead (Stockton).
21 „ = 1 „ „ (Newcastle).
19½ „ = 1 „ „ (London).

FLUXES.—There are numerous substances which being themselves easily fused, are added to more refractory materials to promote their fusion; the following articles are largely used for this purpose—crude tartar, commercial cream of tartar, borax, nitre, sal ammoniac, common salt, limestone, glass, and fluor spar.

As most metals are more disposed to oxidize when in a molten state than when solid, it is usual to cover the surface of the metal in the crucible or smelting pot with some flux, to protect the metal from the action of the air. In the cupola the slag from the lime answers this purpose. With the precious metals powdered charcoal is frequently used, as are also borax and saltpetre. Brass-founders employ the broken glass or powdered charcoal. For the more fusible metals resin and oil are used.

Black Flux.—Nitre 1 part, cream of tartar 2 parts; mix and burn in small quantities in a red-hot crucible, and mix the product with finely powdered charcoal. Keep dry in an air-tight vessel, or well cork the bottle.

This is used in smelting metallic ores.

Flux for Reducing Arsenic.—Carbonate of soda in crystals 8 parts, finely powdered charcoal 1 part; heat gradually to a red heat.

Cornish Reducing Flux.—Crude tartar 10 parts, nitre 4, borax 3; powder together.

Refining Flux.—Crude tartar and nitre, equal parts; burn together.

Crude Flux.—Same as the black flux, omitting the burning in the crucible.

Fluxes for Arsenical Compounds.

1. Dry carbonate of potassa 3 parts, cyanide of potassium 1 part.

2. Dry carbonate of soda and cyanide of potassium equal parts.

Morreau's Reducing Flux.—Powdered glass free from lead 8 parts, and 1 part each of calcined borax and charcoal; powder well and mix.

Salt Cake.—In smelting expensive metals the use of salt cake as a flux greatly improves the appearance of the metal or alloy; the refuse uniting with the salt cake floats to the surface of the crucible, and is skimmed off.

Metal.	Flux.
Iron or steel.	Borax, or sal ammoniac.
Tinned iron.	Resin, or chloride of zinc.
Copper and brass.	Sal ammoniac, or chloride of zinc.
Zinc.	Chloride of zinc.
Lead.	Tallow or resin.
Lead and tin pipes.	Resin and sweet oil.

LUTES.—These are soft adhesive substances, generally of an earthy composition, used for *closing* vessels to make them air and gas tight, or for *coating* over vessels or parts of vessels, to protect them from the effects of high temperatures.

Stourbridge Clay in fine powder, made into a paste with water, will sustain a greater heat than any other English lute.

Windsor Loam, a natural mixture of sand and clay.

Either of the above may be used for coating vessels, or for making tight the hot joints of metallic vessels. Mixtures of pulverized borax with either of the above, or with common clay, form fusible fluxes, useful for glazing over the surfaces of vessels so as to close their pores.

1. Mix thoroughly 2 parts good clay, 8 parts sharp washed sand, and 1 part horse dung, then temper like mortar.

2. Linseed or almond meal mixed to a paste with milk, lime water, or starch paste. This lute stands a temperature of 500°.

Fat Lute.—1. Mix dry clay or pipe-clay in powder with drying linseed oil into a thick paste. The part to which this is applied must be clean and dry.

2. Plaster of Paris mixed with water, milk, or weak glue. Both these lutes stand a dull red heat.

White lead, paste and paper, caoutchouc, and yellow wax, are also used as lutes for various purposes.

Specific Gravity.

The specific gravity of a body is its weight in proportion to that of an equal bulk of water.

The weight of a cubic foot of water at a temperature of 60° is 1000 ounces avoirdupois.

Therefore the specific gravity of a body, water being 1000, shows the weight of a cubic foot of that body in ounces.

Then if the magnitude of the body be known, its weight can be computed; or if its weight be known, its magnitude can be calculated, provided its specific gravity is known. If any two of the three qualities, weight, magnitude, and specific gravity, be known, the third may be calculated by a simple proportion sum.

The specific gravity of metals, mercury excepted, is increased by hammering, rolling, or stamping; it is therefore important, in comparing specific gravities, to consider the treatment to which the metals have been subjected, and also to note their temperatures. High temperatures decrease the specific gravity of metals, as it causes them to increase in bulk.

	Specific Gravity.
Solder for gold	12·40
Solder for silver	9·84
Soft solder	9·55
Pewter	7·25
Music metal	7·1

TABLE XXXIX.—SPECIFIC GRAVITY AND WEIGHT OF VARIOUS MATERIALS USED IN FOUNDRIES, ETC.

	Specific Gravity.	Cubic Foot in Lbs.	Cubic In. in Ozs.
Borax	1·714	107·1	0·99
Chalk	2·767	172·9	1·60
Coal	1·250	78·1	0·72
Emery	4·000	250·0	2·31
Gypsum, opaque	2·168	135·5	1·25
Grindstone	2·143	133·9	1·24
Limestone	2·945	184·1	1·28
Pumice stone	·915	57·2	0·53
Rotten stone	1·981	123·8	1·14
Salt	2·130	133·1	1·23
Sand	1·520	95·0	0·88
Sulphur, native	2·033	127·1	1·17
Sulphur, melted	1·991	124·4	1·15
Tallow	·945	59·1	·55
Olive oil	·915	57·2	·53
Linseed oil	·932	58·2	·54
Tar	1·015	63·4	·59
Whitelead	3·160	197·5	1·82

	Specific Gravity.
Plaster of Paris, dry	1·4
„ wet	1·6
Portland cement	3·0
Flint glass	3·0
Crown „	2·5
Pottery	2·0
Dry loam	1·4
Papier maché	0·7
Modeller's wax	0·96

TABLE XL.—EXPANSION OF METALS BY HEAT.

In raising the temperature of bars of various metals from 32° F. to 212° F. they are found to expand nearly as follows:—

Platinum	one in 1097 parts.
Palladium	„ 1000 „
Antimony	„ 923 „
Cast iron	„ 901 „
Steel	„ 824 „
Wrought iron	„ 801 „
Bismuth	„ 718 „
Gold	„ 667 „
Copper	„ 557 „
Gun metal (copper 8, tin 1)	„ 550 „
Brass	„ 524 „
Speculum metal	„ 517 „
Silver	„ 499 „
Tin	„ 424 „
Lead	„ 350 „
Zinc	„ 336 „

TABLE XLI.—TO CALCULATE VALUE PER TON OF 2240 LBS. AT $\frac{1}{16}$ OF A 1d. PER LB. TO 1s. PER LB.

d.	£	s.	d.	d.	£	s.	d.	d.	£	s.	d.
$\frac{1}{16}$	0	11	8	$4\frac{1}{8}$	38	10	0	$8\frac{1}{8}$	75	16	8
$\frac{1}{8}$	1	3	4	$4\frac{1}{4}$	39	13	4	$8\frac{1}{4}$	77	0	0
$\frac{1}{4}$	2	6	8	$4\frac{3}{8}$	40	16	8	$8\frac{3}{8}$	78	3	4
$\frac{3}{8}$	3	10	0	$4\frac{1}{2}$	42	0	0	$8\frac{1}{2}$	79	6	8
$\frac{1}{2}$	4	13	4	$4\frac{5}{8}$	43	3	4	$8\frac{5}{8}$	80	10	0
$\frac{5}{8}$	5	16	8	$4\frac{3}{4}$	44	6	8	$8\frac{3}{4}$	81	13	4
$\frac{3}{4}$	7	0	0	$4\frac{7}{8}$	45	10	0	$8\frac{7}{8}$	82	16	8
$\frac{7}{8}$	8	3	4	5	46	13	4	9	84	0	0
1	9	6	8	$5\frac{1}{8}$	47	16	8	$9\frac{1}{8}$	85	3	4
$1\frac{1}{8}$	10	10	0	$5\frac{1}{4}$	49	0	0	$9\frac{1}{4}$	86	6	8
$1\frac{1}{4}$	11	13	4	$5\frac{3}{8}$	50	3	4	$9\frac{3}{8}$	87	10	0
$1\frac{3}{8}$	12	16	8	$5\frac{1}{2}$	51	6	8	$9\frac{1}{2}$	88	13	4
$1\frac{1}{2}$	14	0	0	$5\frac{5}{8}$	52	10	0	$9\frac{5}{8}$	89	16	8
$1\frac{5}{8}$	15	3	4	$5\frac{3}{4}$	53	13	4	$9\frac{3}{4}$	91	0	0
$1\frac{3}{4}$	16	6	8	$5\frac{7}{8}$	54	16	8	$9\frac{7}{8}$	92	3	4
$1\frac{7}{8}$	17	10	0	6	56	0	0	10	93	6	8
2	18	13	4	$6\frac{1}{8}$	57	3	4	$10\frac{1}{8}$	94	10	0
$2\frac{1}{8}$	19	16	8	$6\frac{1}{4}$	58	6	8	$10\frac{1}{4}$	95	13	4
$2\frac{1}{4}$	21	0	0	$6\frac{3}{8}$	59	10	0	$10\frac{3}{8}$	96	16	8
$2\frac{3}{8}$	22	3	4	$6\frac{1}{2}$	60	13	4	$10\frac{1}{2}$	98	0	0
$2\frac{1}{2}$	22	16	8	$6\frac{5}{8}$	61	16	8	$10\frac{5}{8}$	99	3	4
$2\frac{5}{8}$	24	10	0	$6\frac{3}{4}$	63	0	0	$10\frac{3}{4}$	100	6	8
$2\frac{3}{4}$	25	13	4	$6\frac{7}{8}$	64	3	4	$10\frac{7}{8}$	101	10	0
$2\frac{7}{8}$	26	16	8	7	65	6	8	11	102	13	4
3	28	0	0	$7\frac{1}{8}$	66	10	0	$11\frac{1}{8}$	103	16	8
$3\frac{1}{8}$	29	3	4	$7\frac{1}{4}$	67	13	4	$11\frac{1}{4}$	105	0	0
$3\frac{1}{4}$	30	6	8	$7\frac{3}{8}$	68	16	8	$11\frac{3}{8}$	106	3	4
$3\frac{3}{8}$	31	10	0	$7\frac{1}{2}$	70	0	0	$11\frac{1}{2}$	107	6	8
$3\frac{1}{2}$	32	13	4	$7\frac{5}{8}$	71	3	4	$11\frac{5}{8}$	108	10	0
$3\frac{5}{8}$	33	16	8	$7\frac{3}{4}$	72	6	8	$11\frac{3}{4}$	109	13	4
$3\frac{3}{4}$	35	0	0	$7\frac{7}{8}$	73	10	0	$11\frac{7}{8}$	110	16	8
$3\frac{7}{8}$	36	3	4	8	74	13	4	1s.	112	0	0
4	37	6	8								

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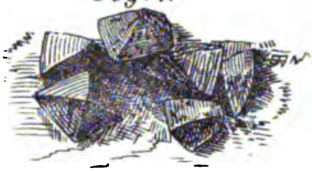
Plate I.

Fig. 1.



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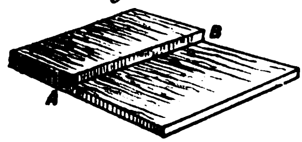
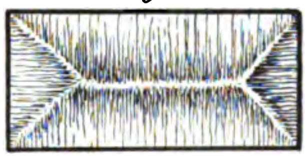


Fig. 3.

Fig. 4.



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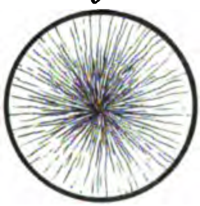

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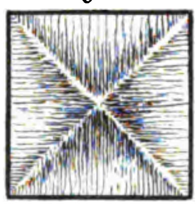

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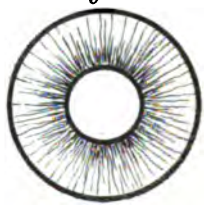


Fig. 9.

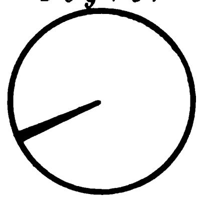
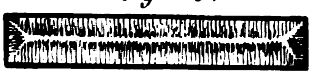


Fig. 8.



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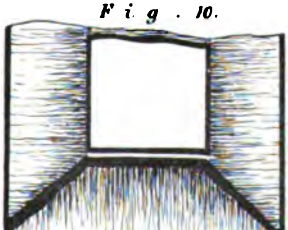
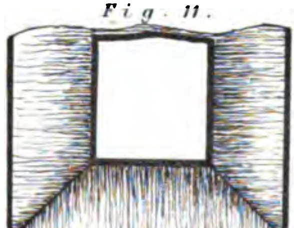


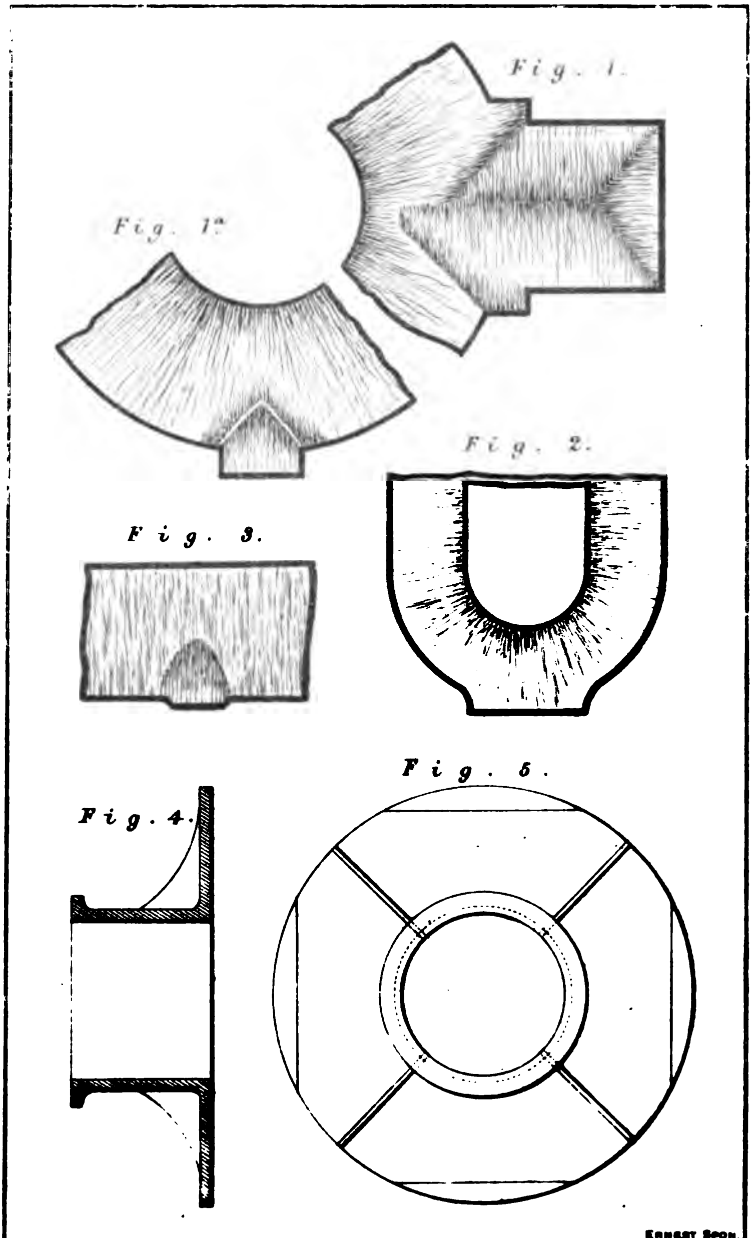
Fig. 11.



Ernest Spon.

E & F N Spon, London & New York

Plate II



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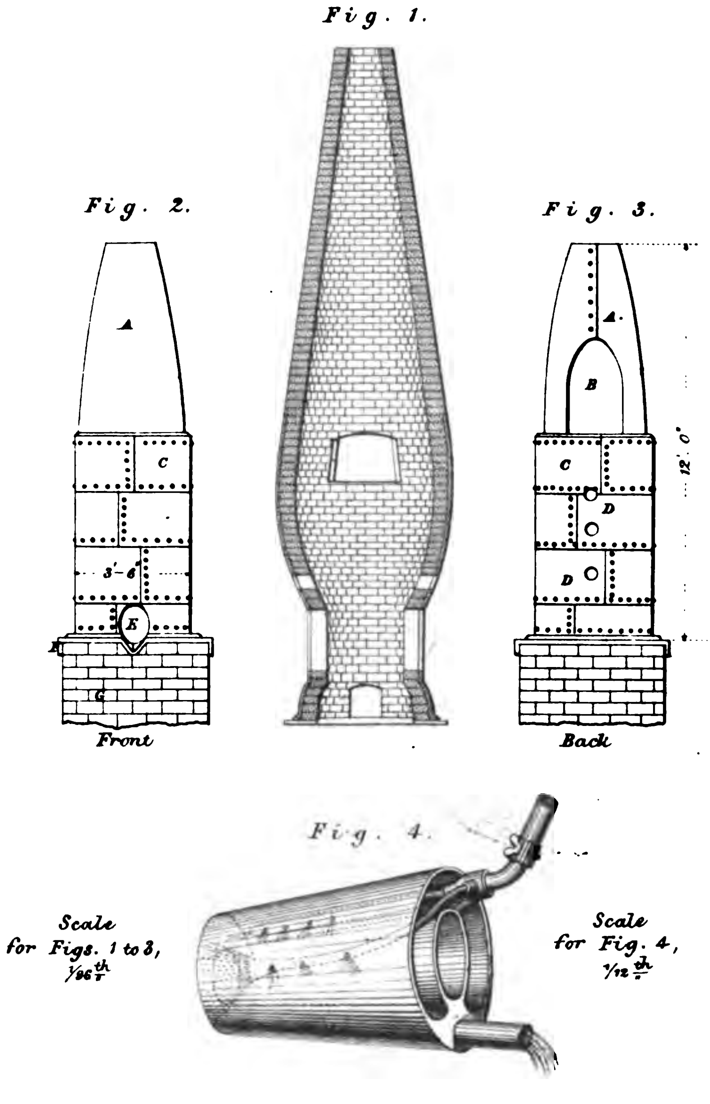
CUPOLAS.



ERNEST SPON.

E. & F. N. Spon, London & New York

CUPOLAS.

Fig. 1.

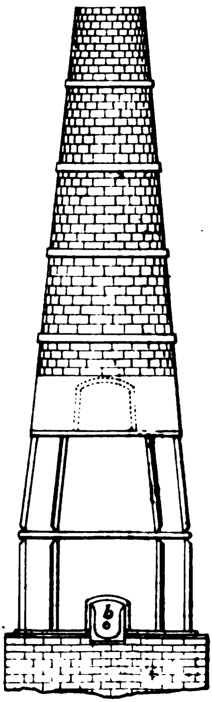


Fig. 2.

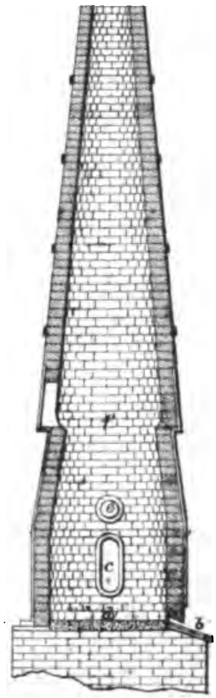


Fig. 4.

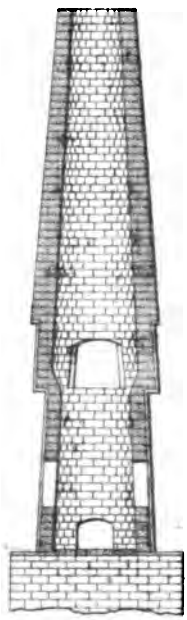
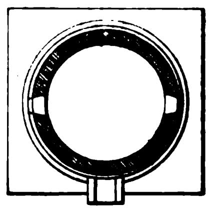


Fig. 3.



Scale, 1/96th.

1/8th" — 1'

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CUPOLAS.

Fig. 1.

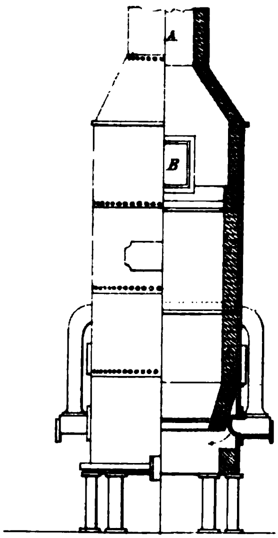


Fig. 2.

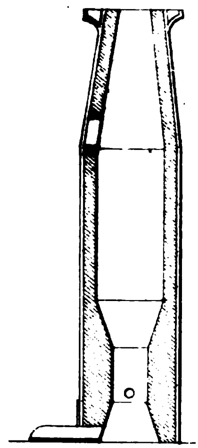


Fig. 3.

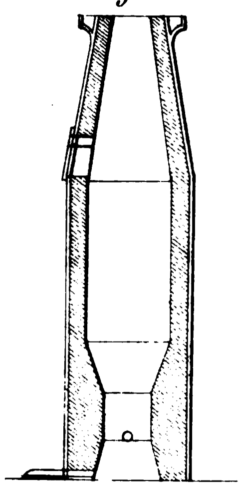
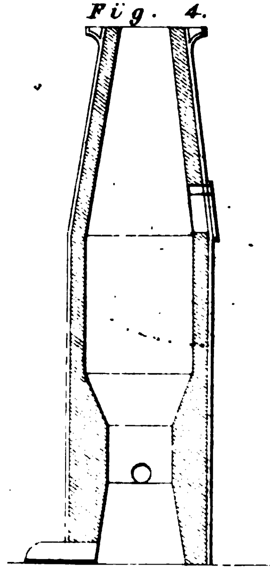


Fig. 4.



ERNEST SPON.

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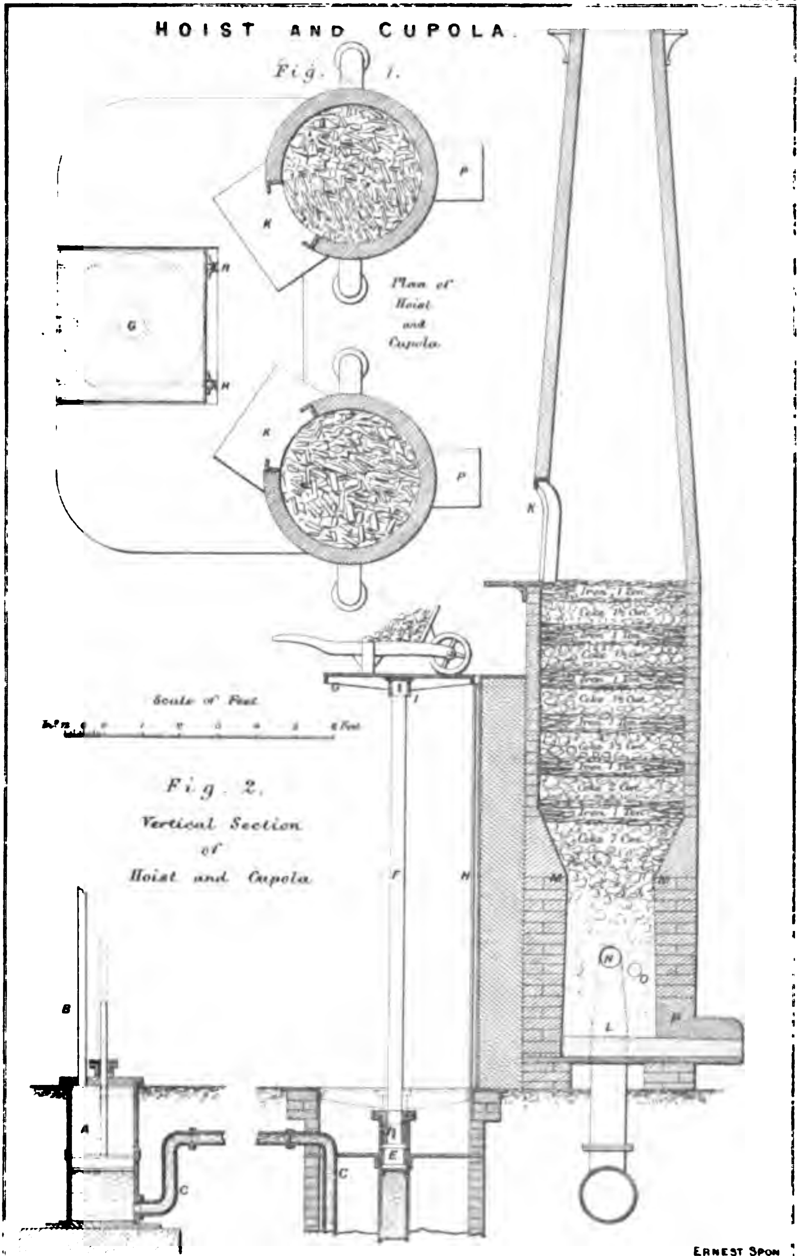

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CUPOLAS.

Scale $\frac{1}{96}$*th*

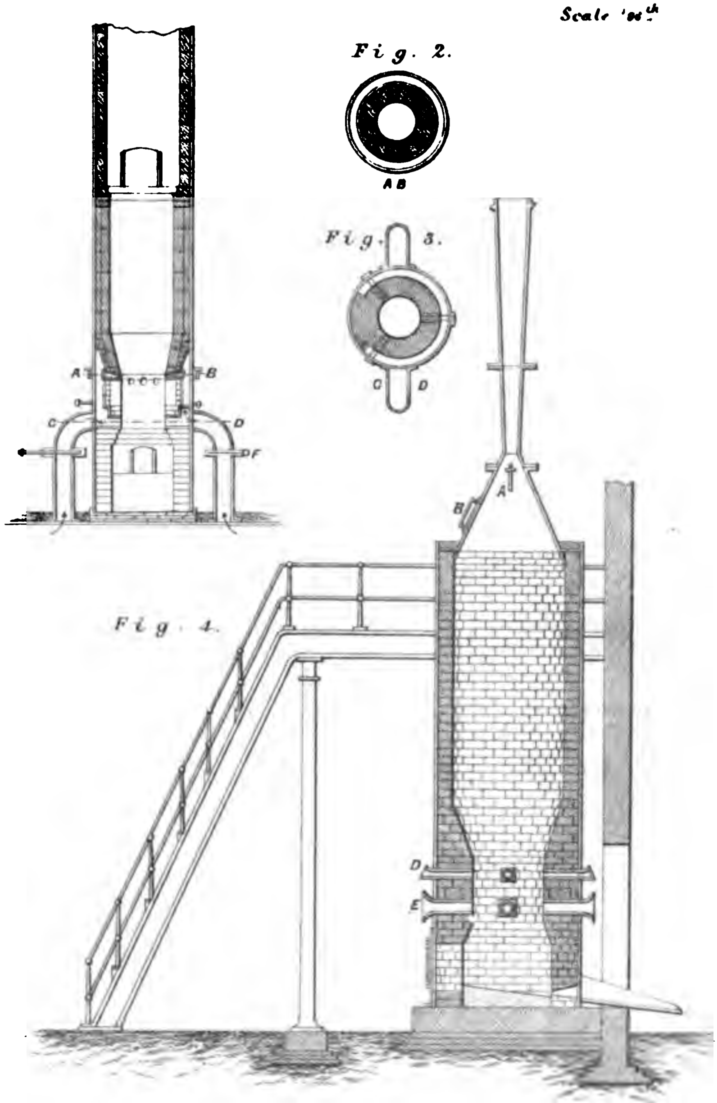

Fig. 2.

Fig. 3.

Fig. 4.

ERNEST SPON.

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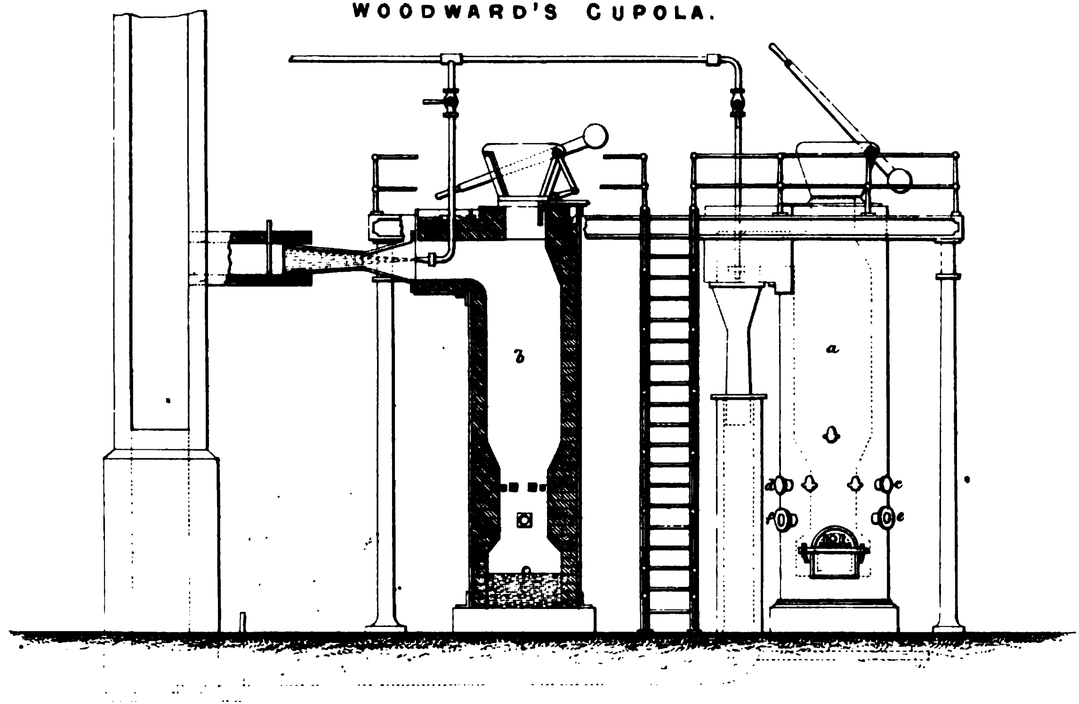
Plate VIII

WOODWARD'S CUPOLA.

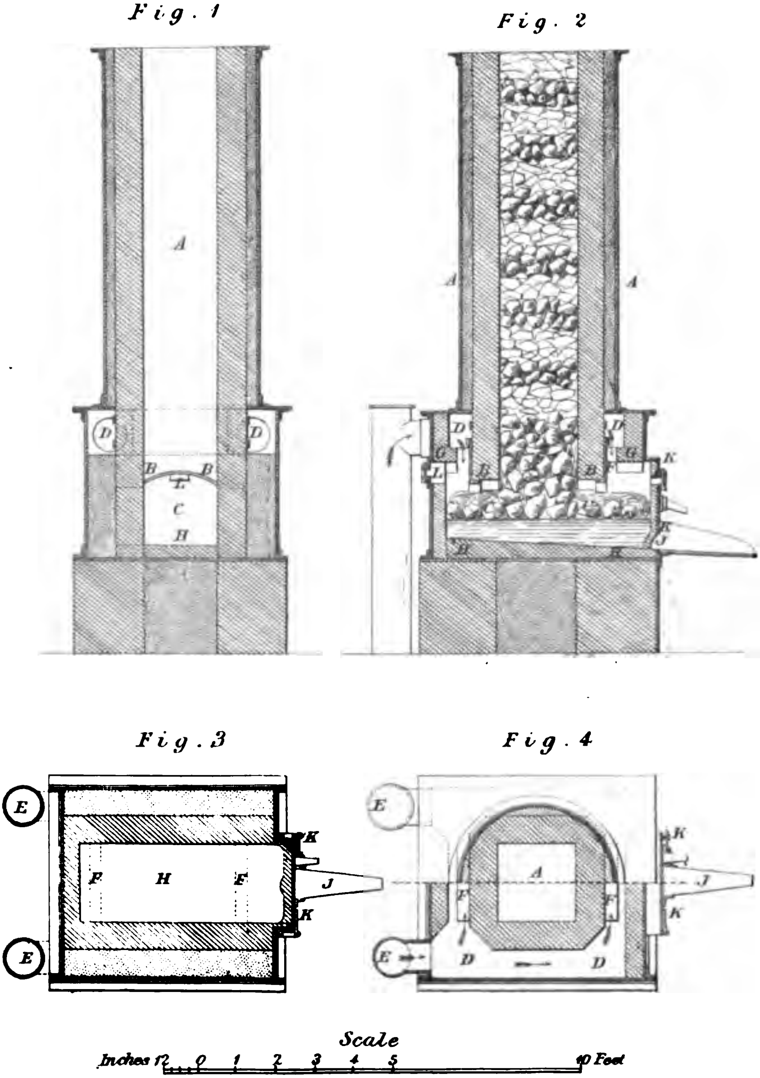


Scale, 1/96th. 1/8th" – 1 ft.

ERNEST SPON.

E. & F. N. Spon, London & New York.

KRIGAR'S CUPOLA.

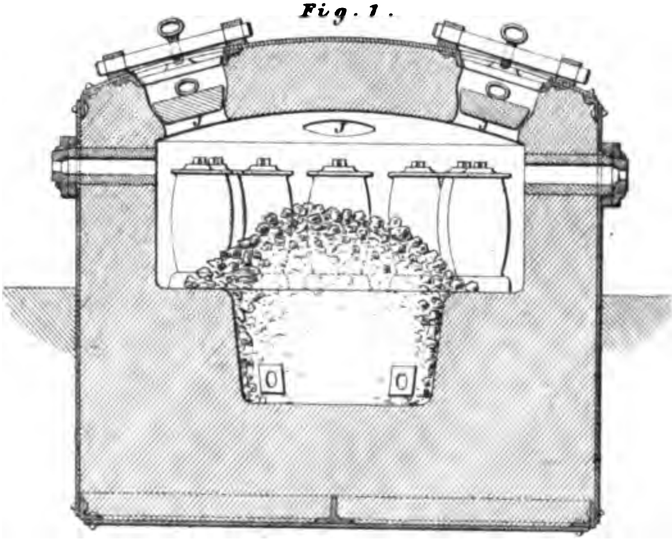


ERNEST SPON.

E & F N. Spon, London & New York

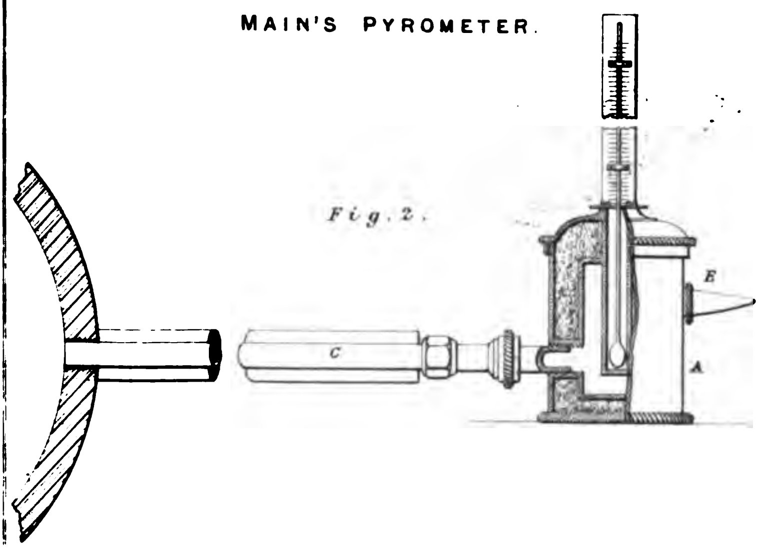
AIR FURNACE.

Fig. 1.



MAIN'S PYROMETER.

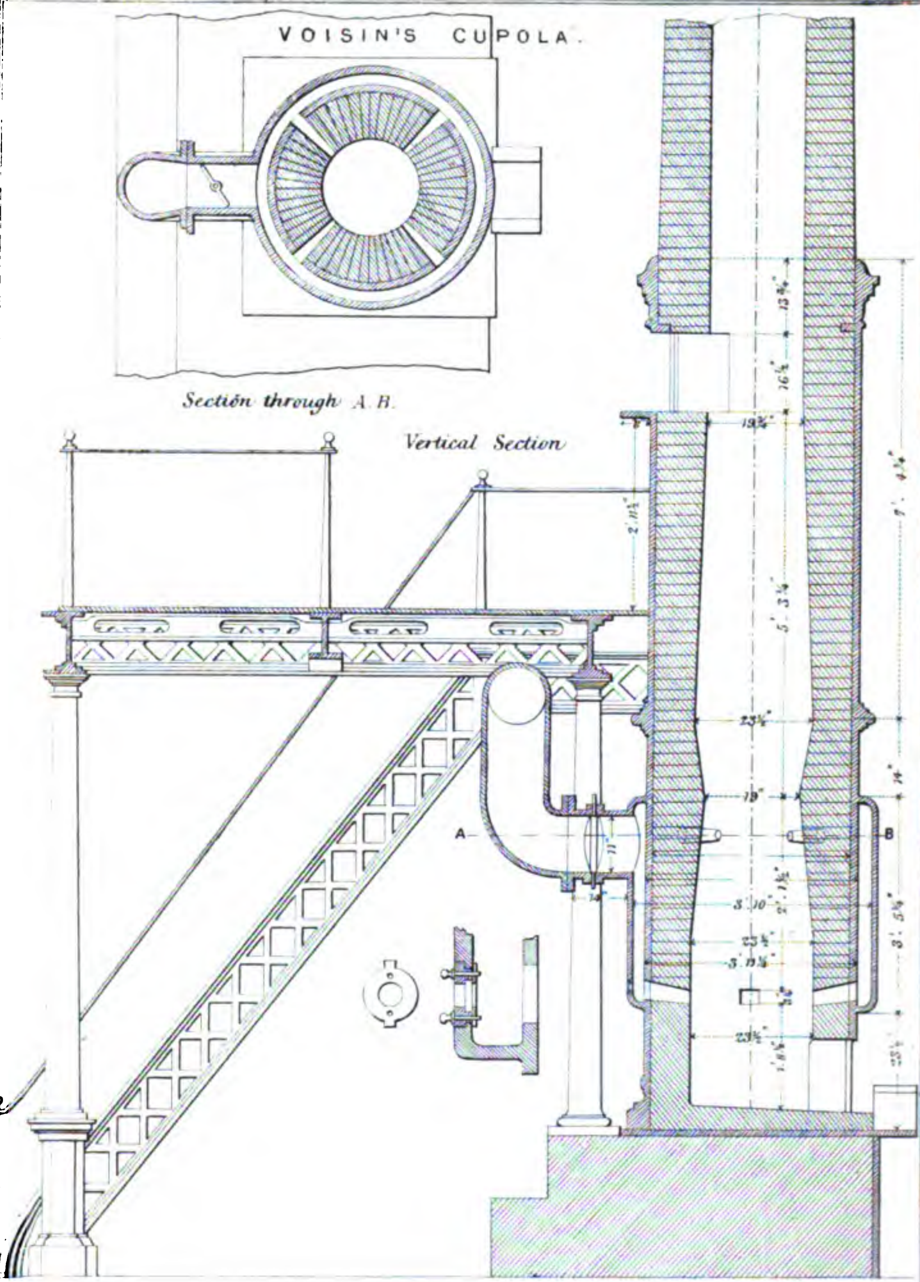
Fig. 2.



ERNEST SPON.

E & F N Spon, London & New York

VOISIN'S CUPOLA.



Ernest Spon.
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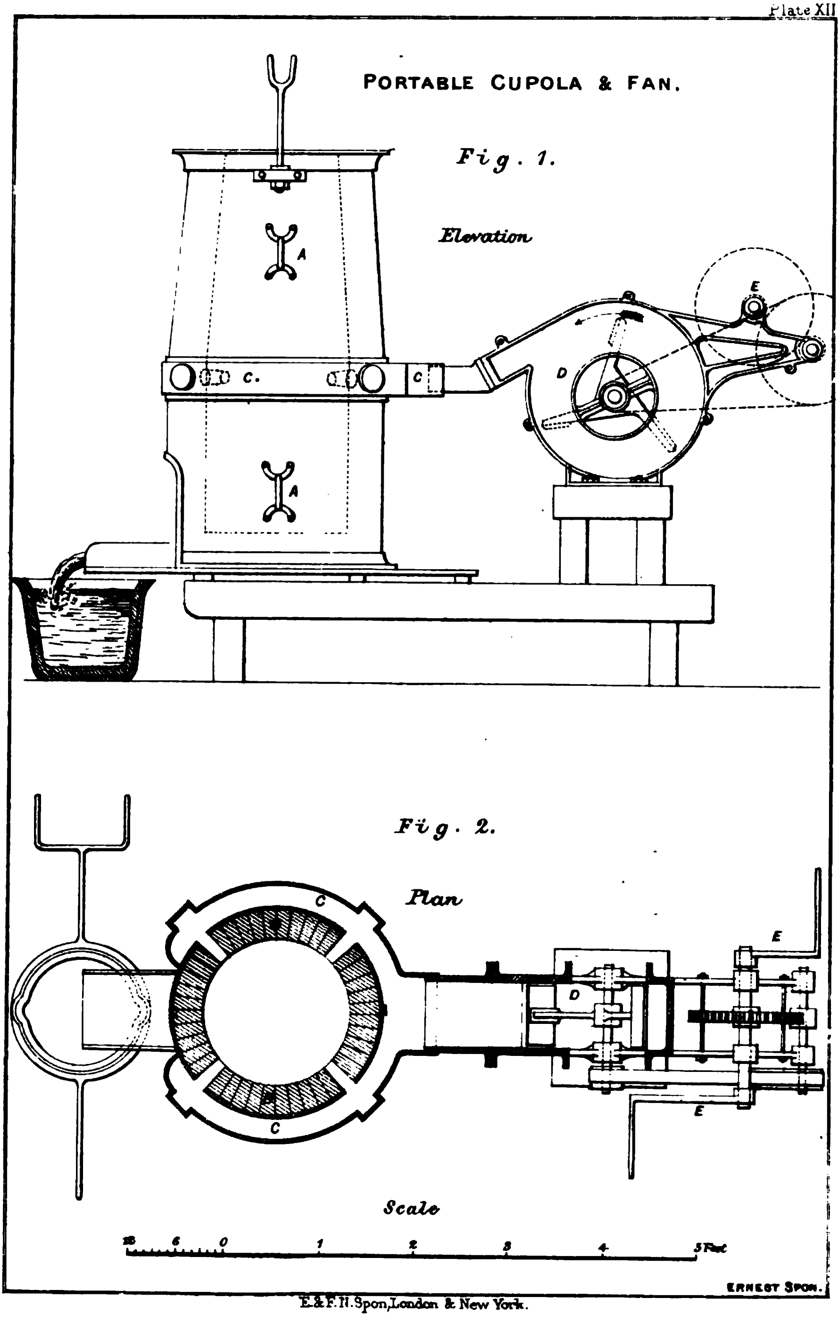

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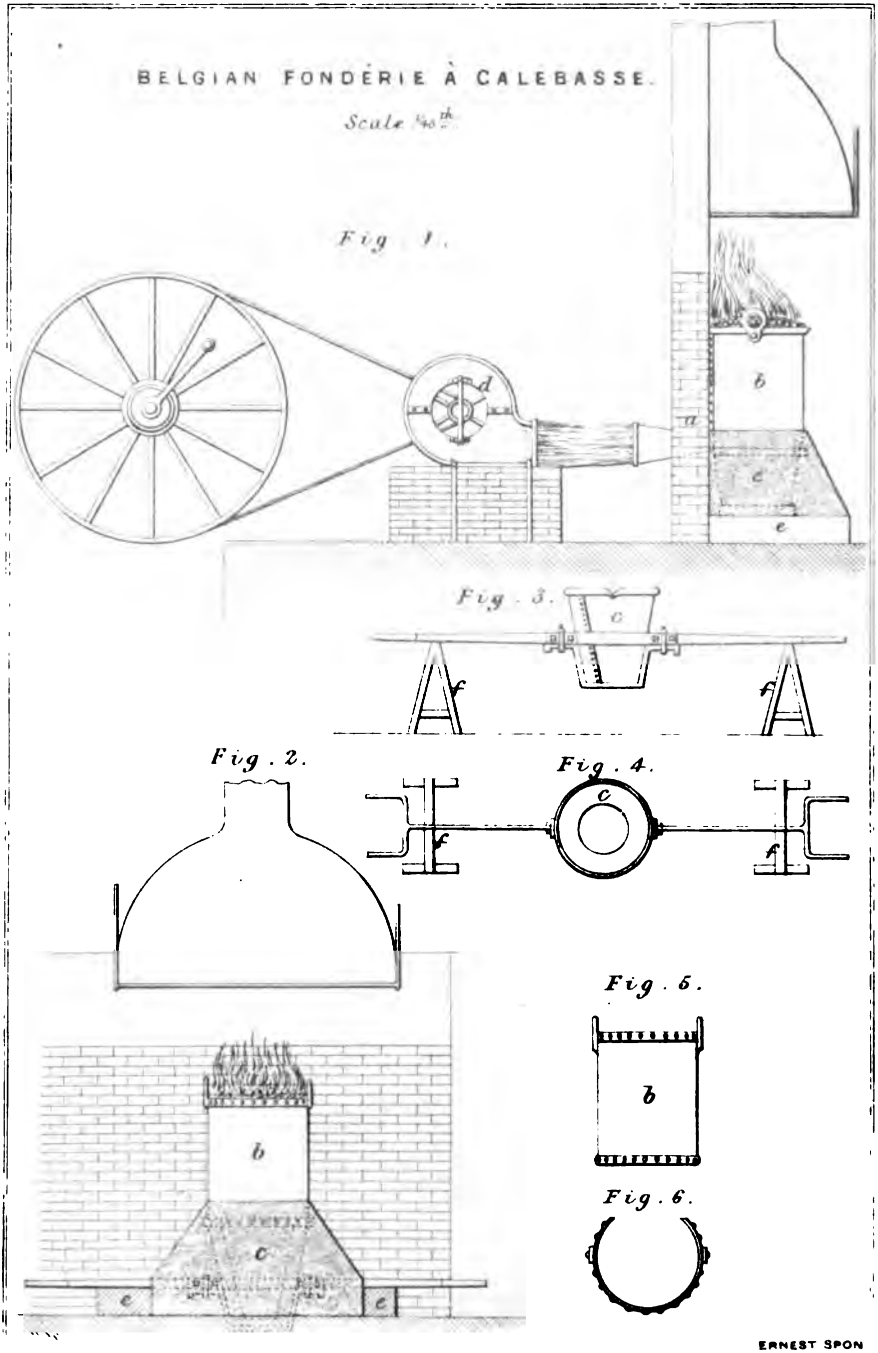
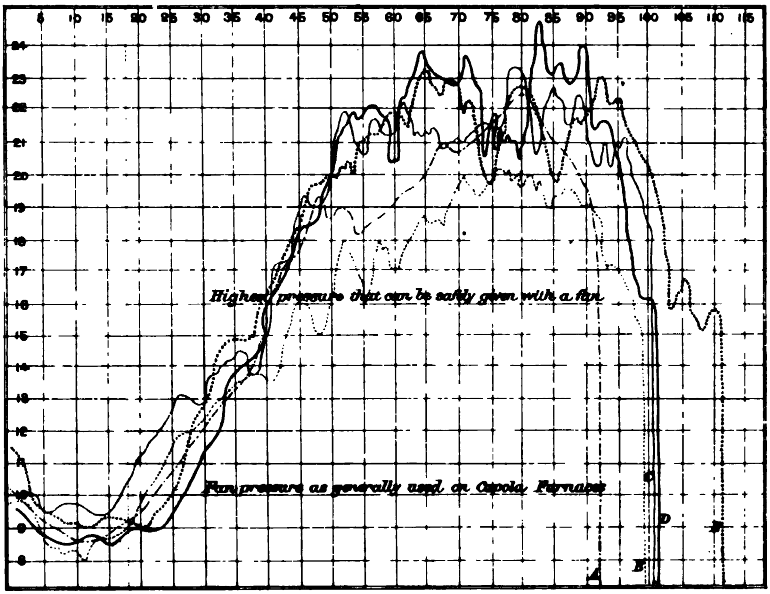


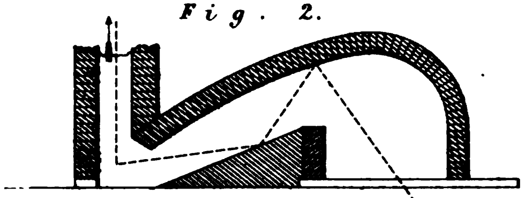
E. & F. N. Spon. London & New York.

Fig. 1.



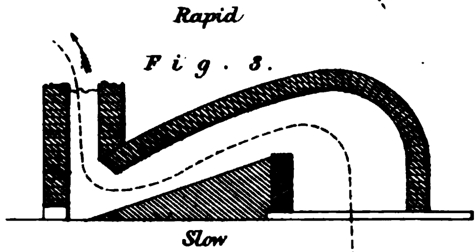
AIR FURNACES.

Fig. 2.



Rapid

Fig. 3.



Slow

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AIR FURNACES.

Fig. 1.

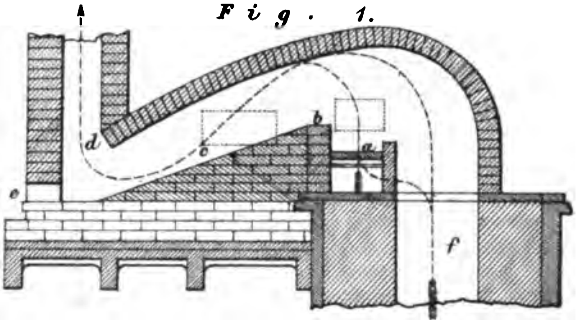

Fig. 2.

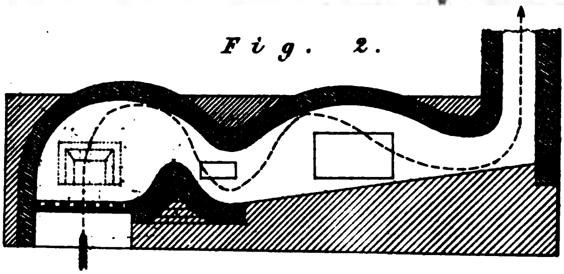

Fig. 3.

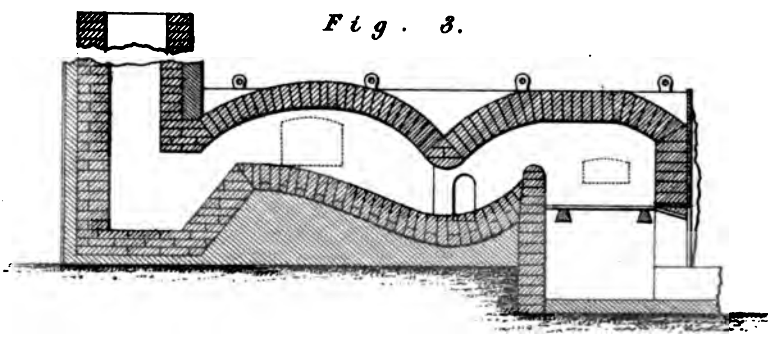

Fig. 4.

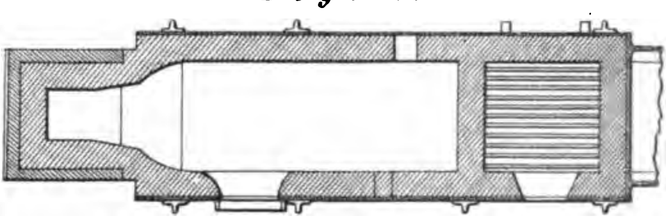

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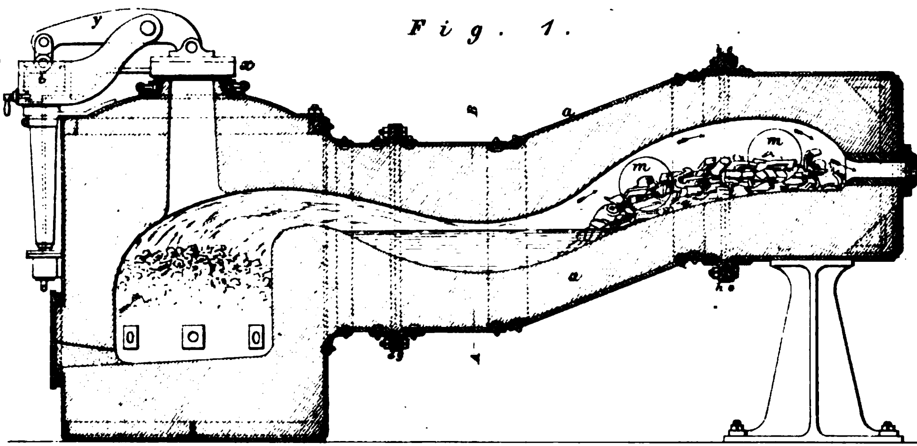
Plate XVI

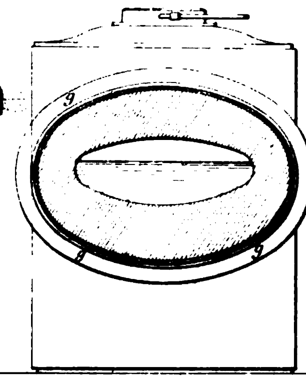
AIR FURNACES.

Fig. 1.



Longitudinal Section.

Fig. 2.



Cross Section at A. B.

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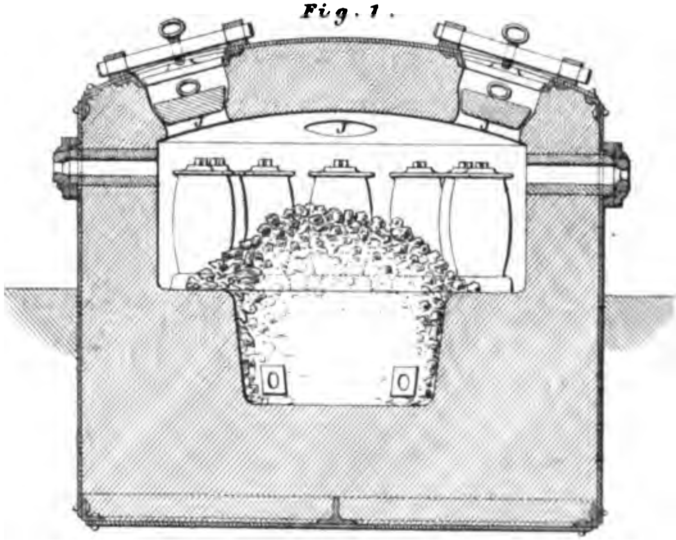
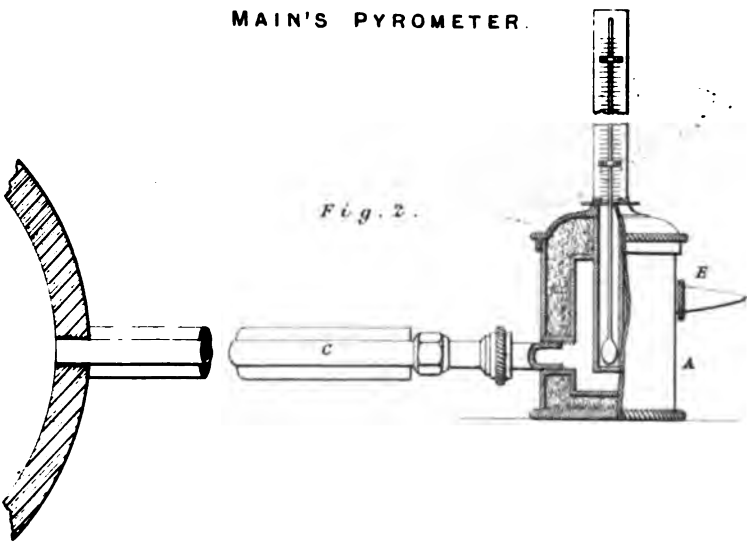
AIR FURNACE.

Fig. 1.



MAIN'S PYROMETER.

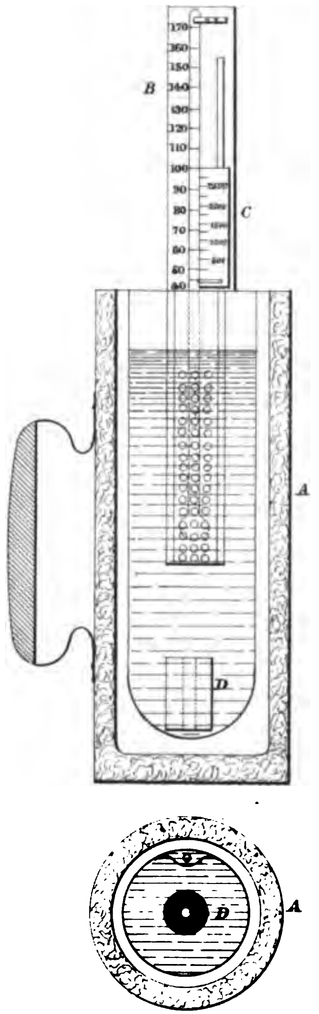
Fig. 2.



ERNEST SPON.

E. & F. N. Spon, London & New York

WILSON'S PYROMETER.



Scale ¼th

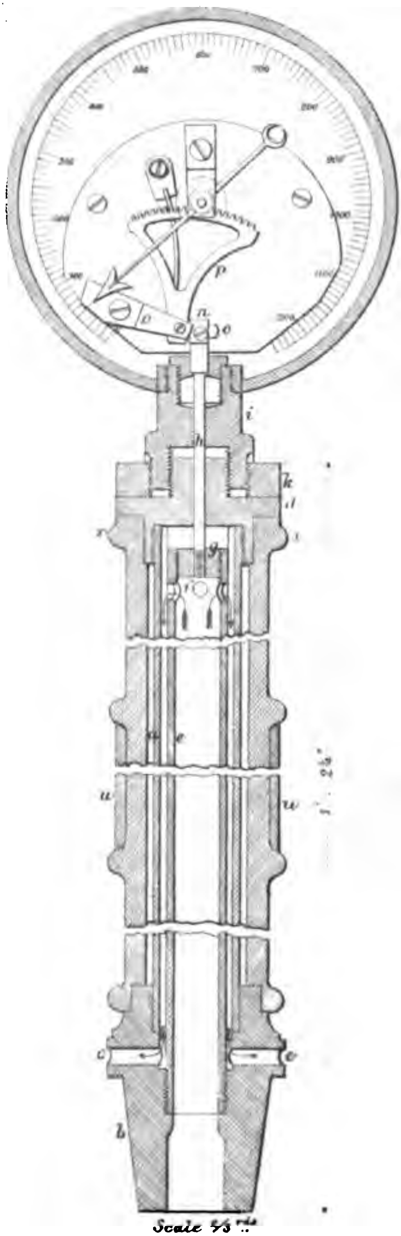
0 1 2 3 4 ins.

E. & F. N. Spon, London & New York

ERNEST SPON

Plate XVIII

CARSATELLI'S PYROMETER.



Scale ⅔rds

ERNEST SPON.

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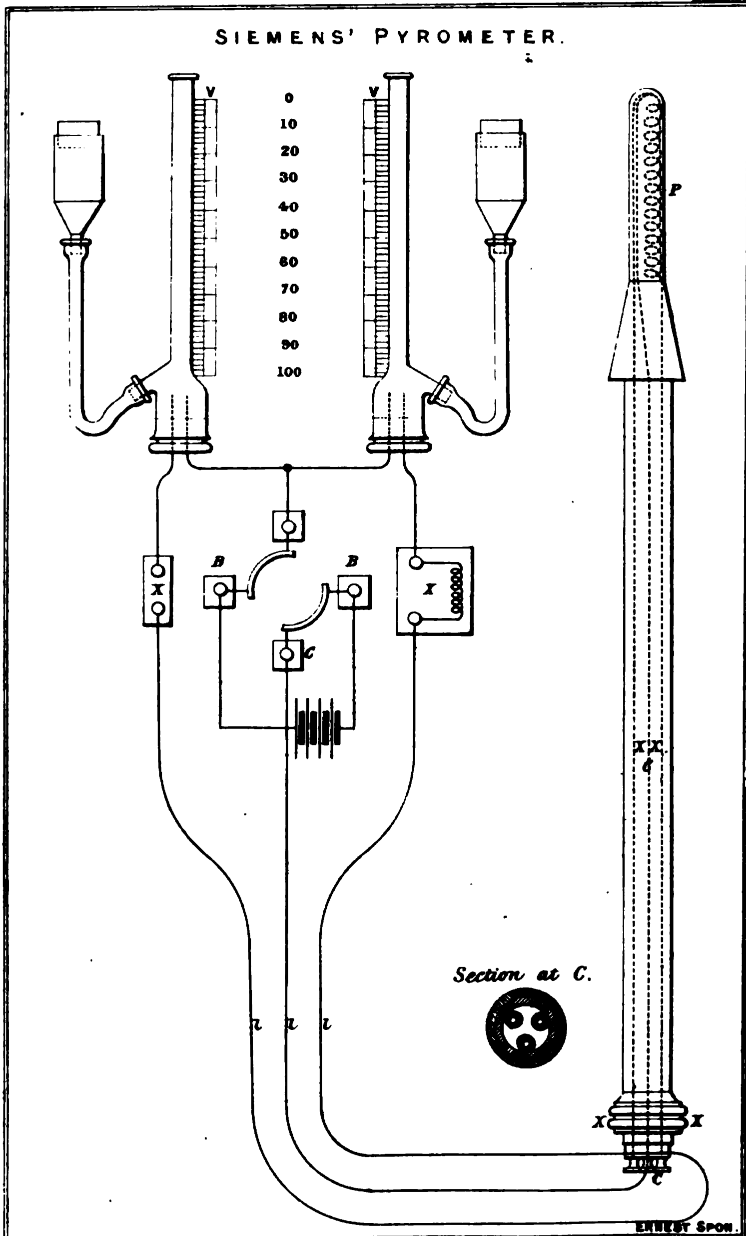
Plate XX.



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CRUCIBLE MOULDING MACHINE.

Fig 1.

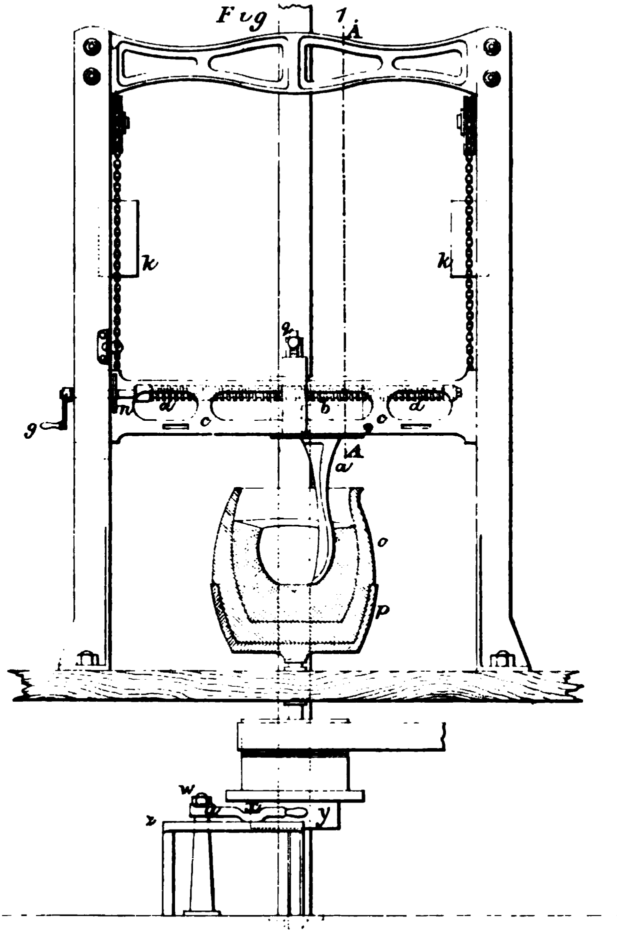


Fig. 2.

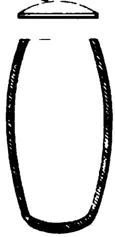
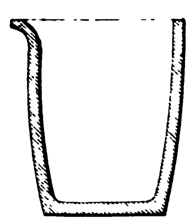
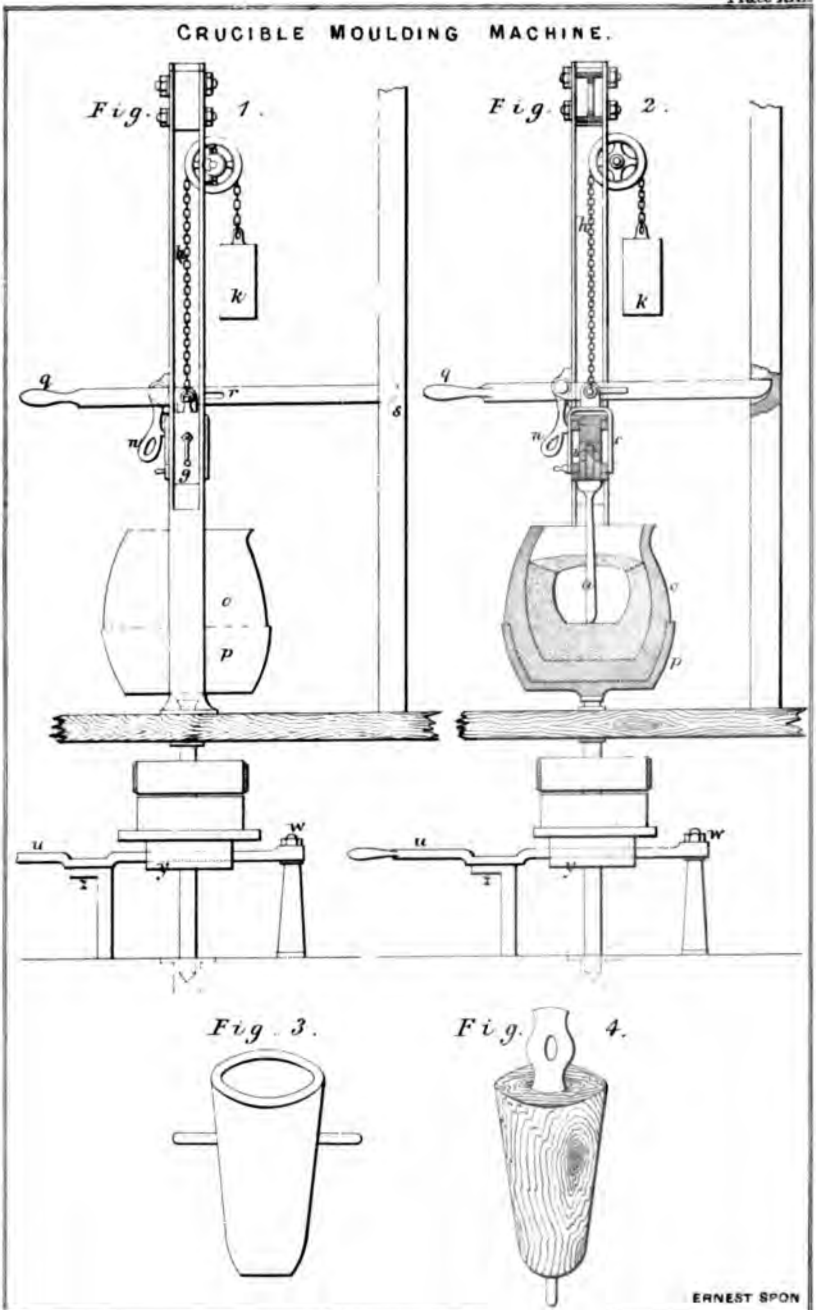


Fig 3.



ERNEST SPON.

E. & F. N. Spon, London & New York



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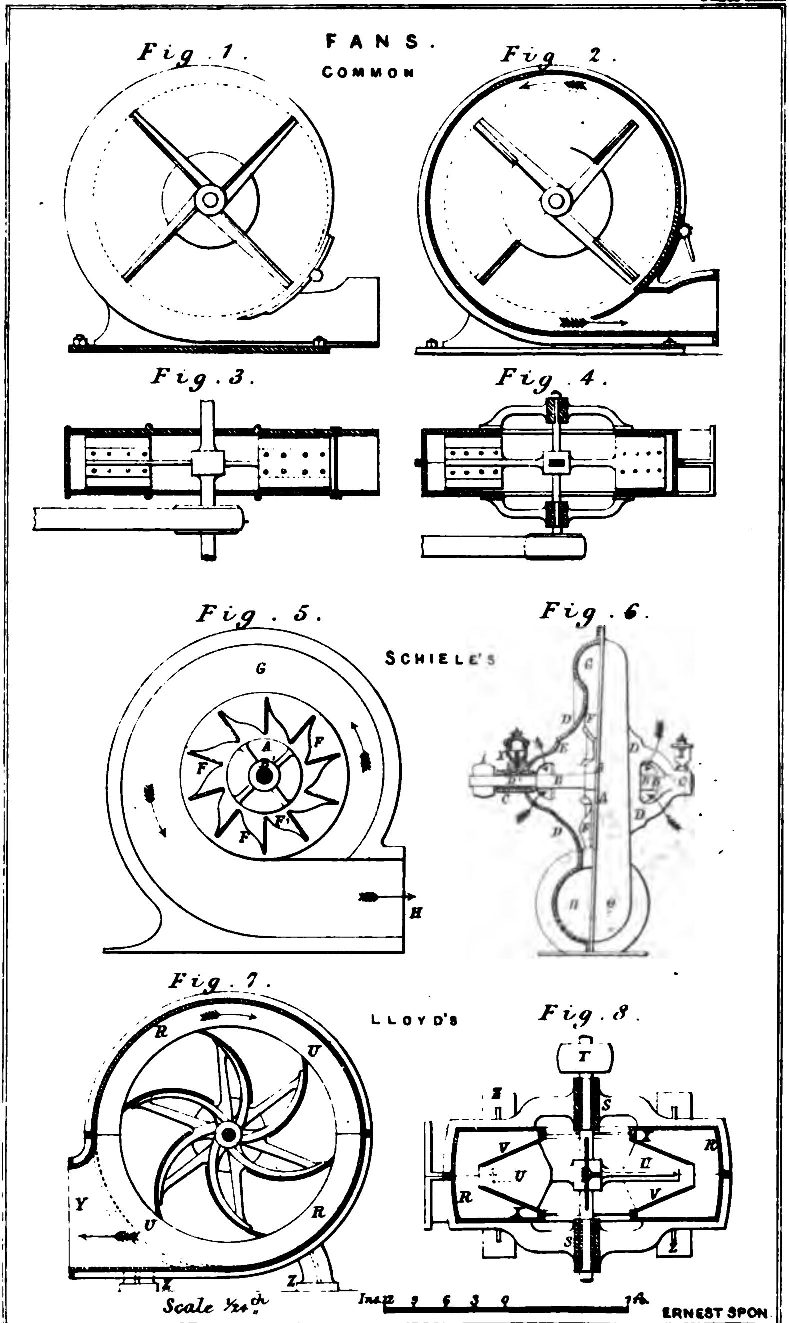
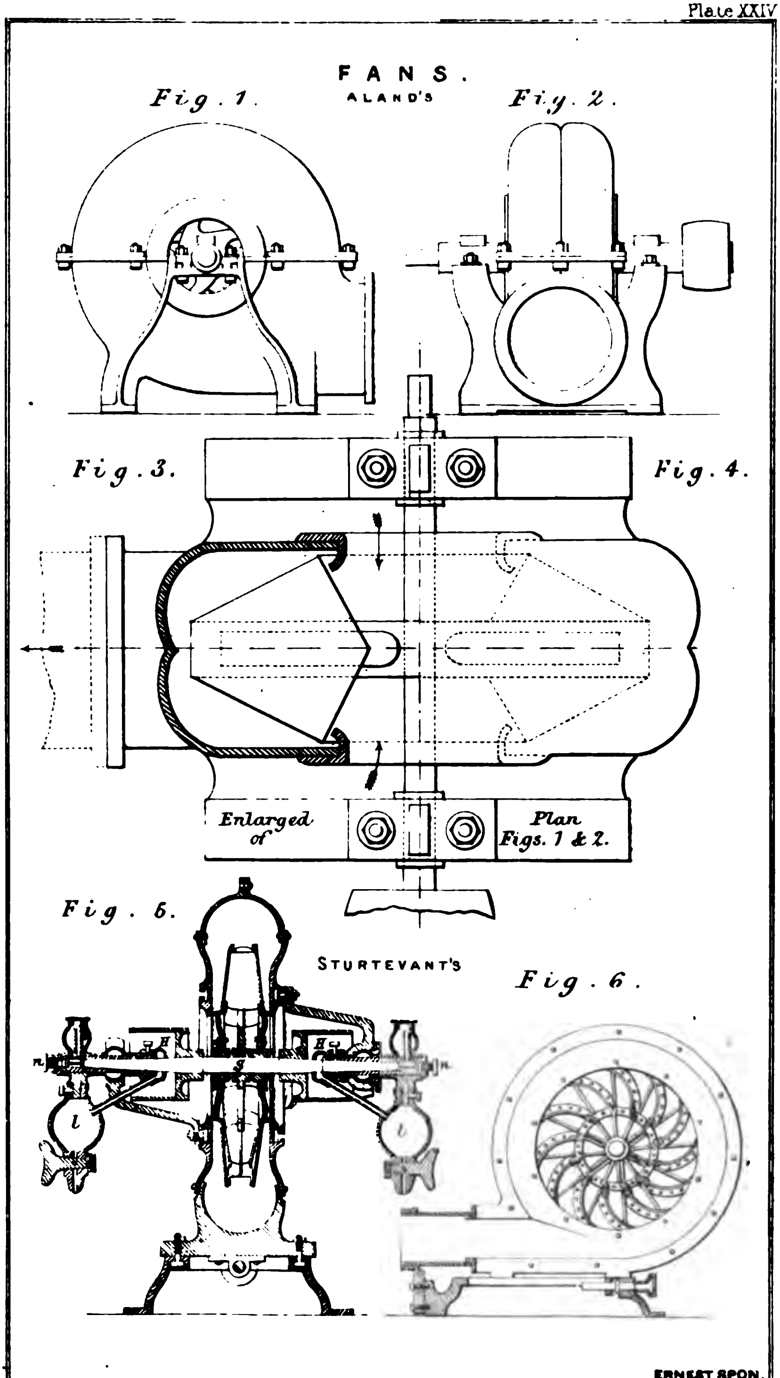


E & F. N Spon. London & New York.



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BLOWERS.

GYNNE'S

Fig. 1.

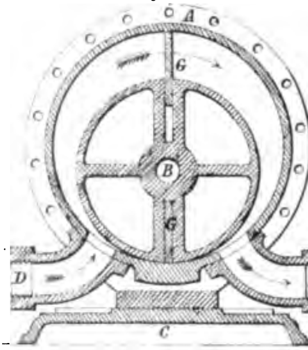


Fig. 2.

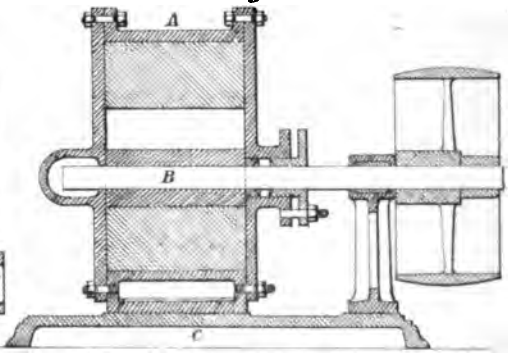


Fig. 3.

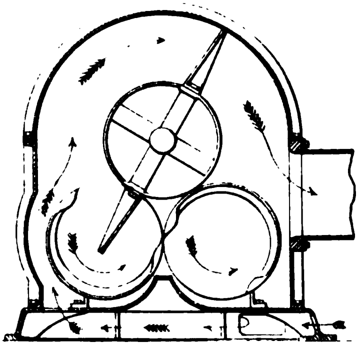
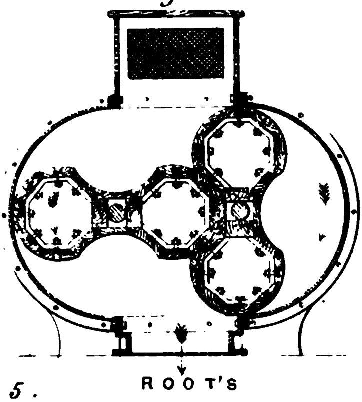


Fig. 4.

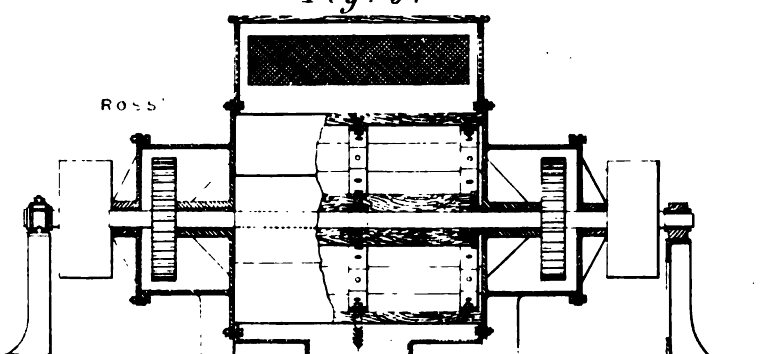


BAKER'S

ROOT'S

Fig. 5.

ROSS'



Scale. Figs. 1 & 2. 1/16th
" Figs. 3 to 5. 1/30th "

Scale
0 1 2 3 4

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PATTERN MAKING TOOLS.

Fig. 1.

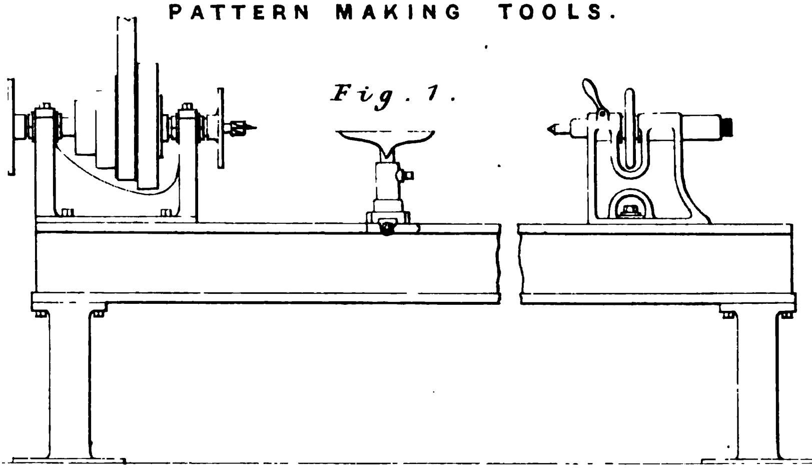


Fig. 2.

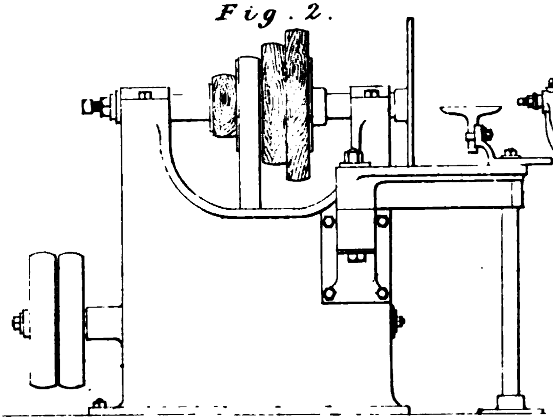


Fig. 3.

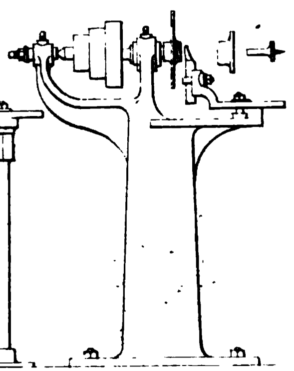
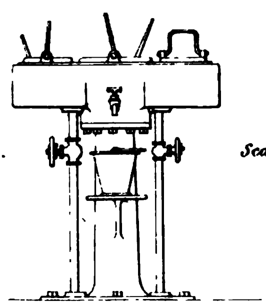


Fig. 4.



Scale 1/24th

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MOULDING.

Fig. 1. Fig. 2. Fig. 3.

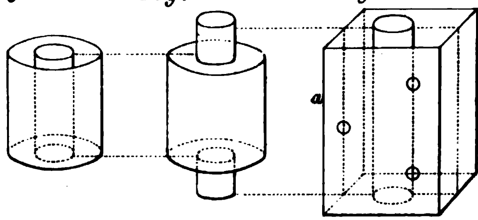


Fig. 4.

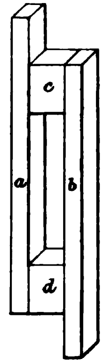


Fig. 5.

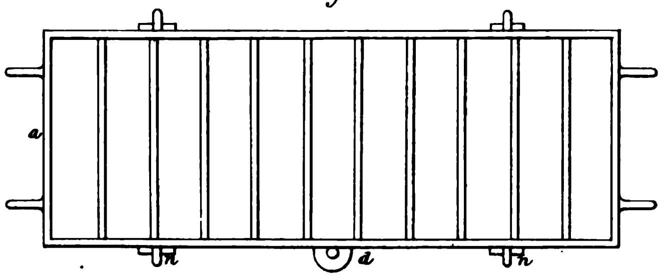


Fig. 6.

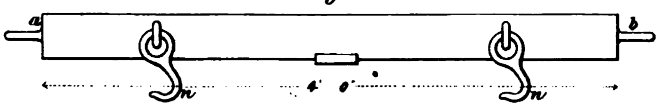


Fig. 7.

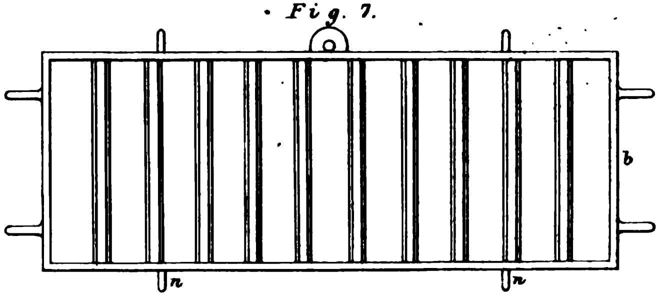
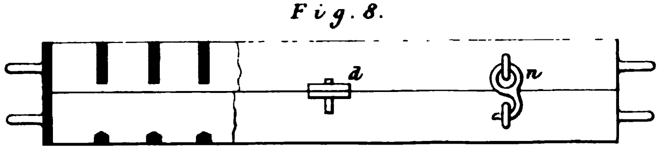


Fig. 8.



ERNEST SPON.

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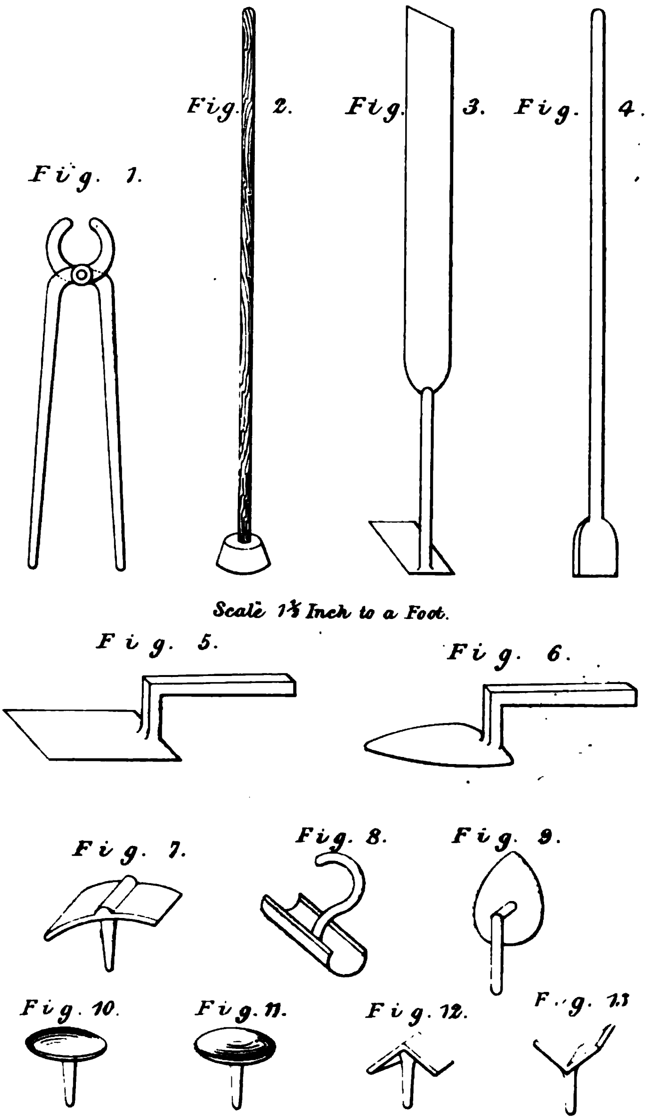
MOULDING TOOLS.



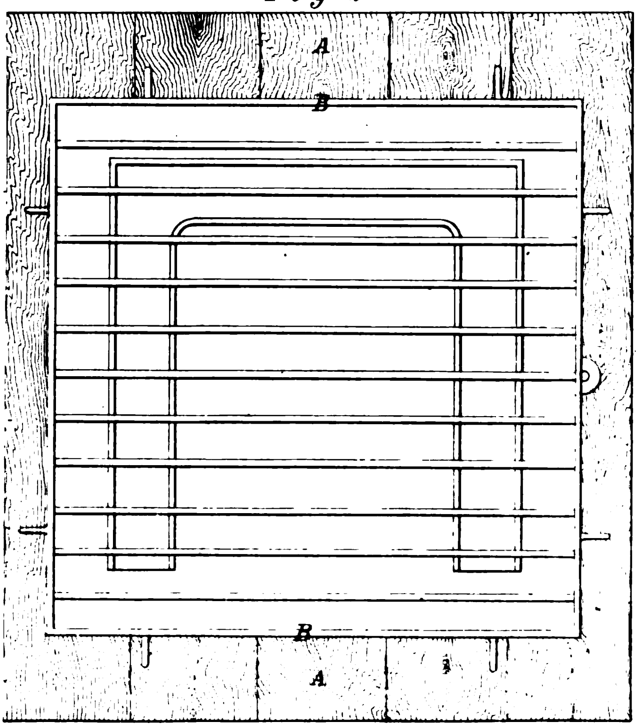
ERNEST SPON

E. & F. N. Spon, London & New York.

MOULDING.

Fig. 1.

Fig. 2.



ERNEST SPON

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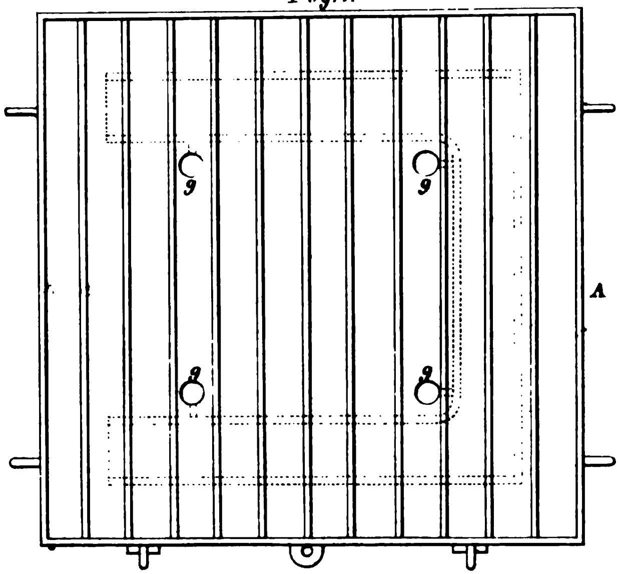
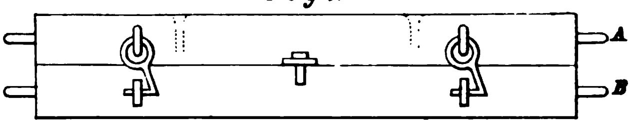
MOULDING.

Fig. 1.



Plan.

Fig. 2.



Elevation.

CASTING ON.

Fig. 7.

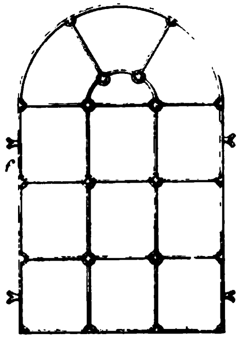


Fig. 3.

Inner Bar

Fig. 4

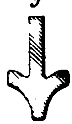
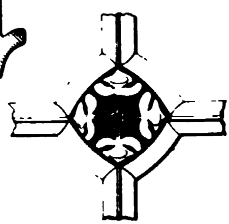


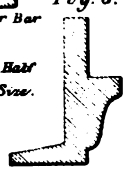
Fig. 5



Cast Iron Boss

Fig. 6.

Half Size.



Outer Bar.
with Rib Rolled on.

Ernest Spon.

E & F. N. Spon, London & New York

MOULDING.

Fig. 1.

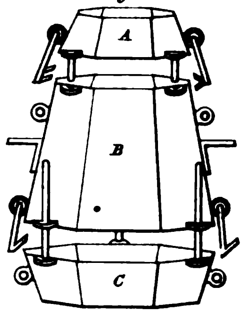


Fig. 2.

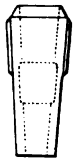


Fig. 3.

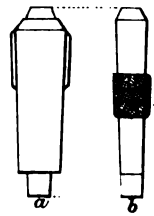


Fig. 5.

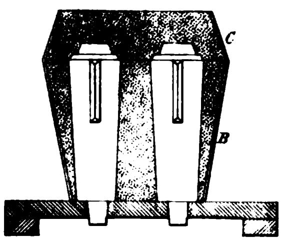


Fig. 4.

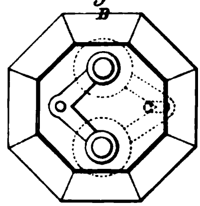


Fig. 6.

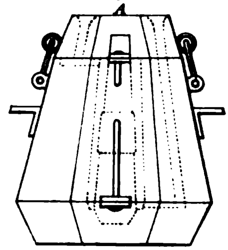


Fig. 7.

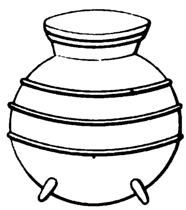
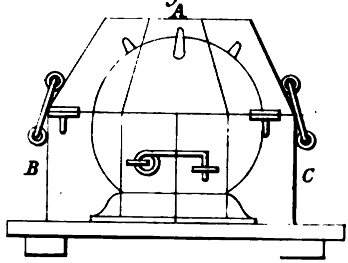


Fig. 8.



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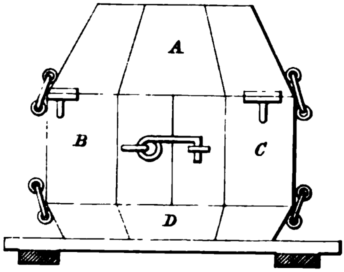
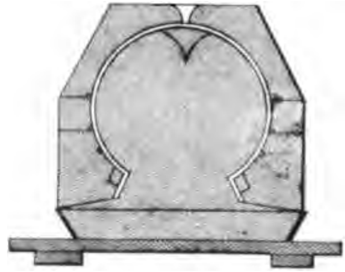


Fig. 10.



Ernest Spon.

E & F N Spon, London & New York.

FLAT MOULDING.

Fig. 1.

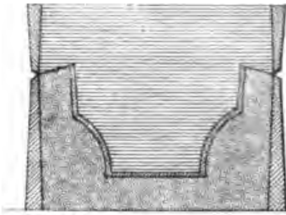


Fig. 2.

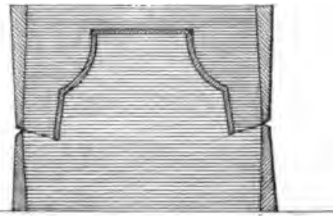


Fig. 3.

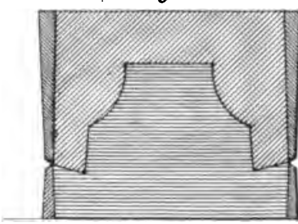


Fig. 4.

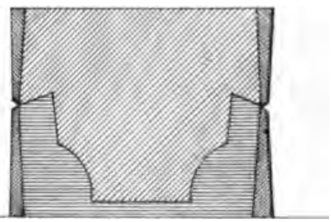


Fig. 5.

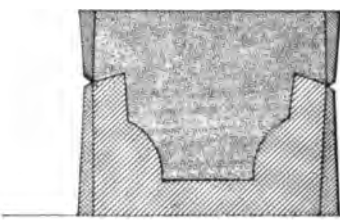


Fig. 6.

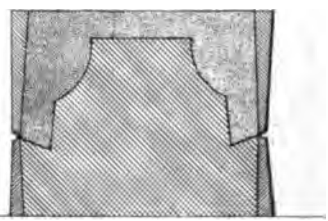
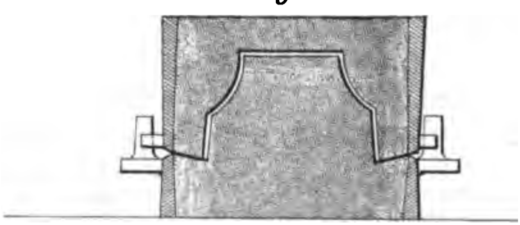


Fig. 7.



Scale, 1/8th

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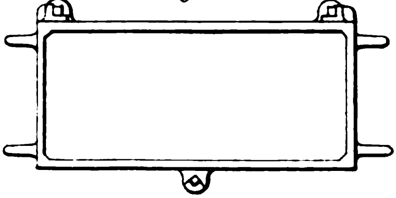
FLAT MOULDING.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.



Scale, 1/16th

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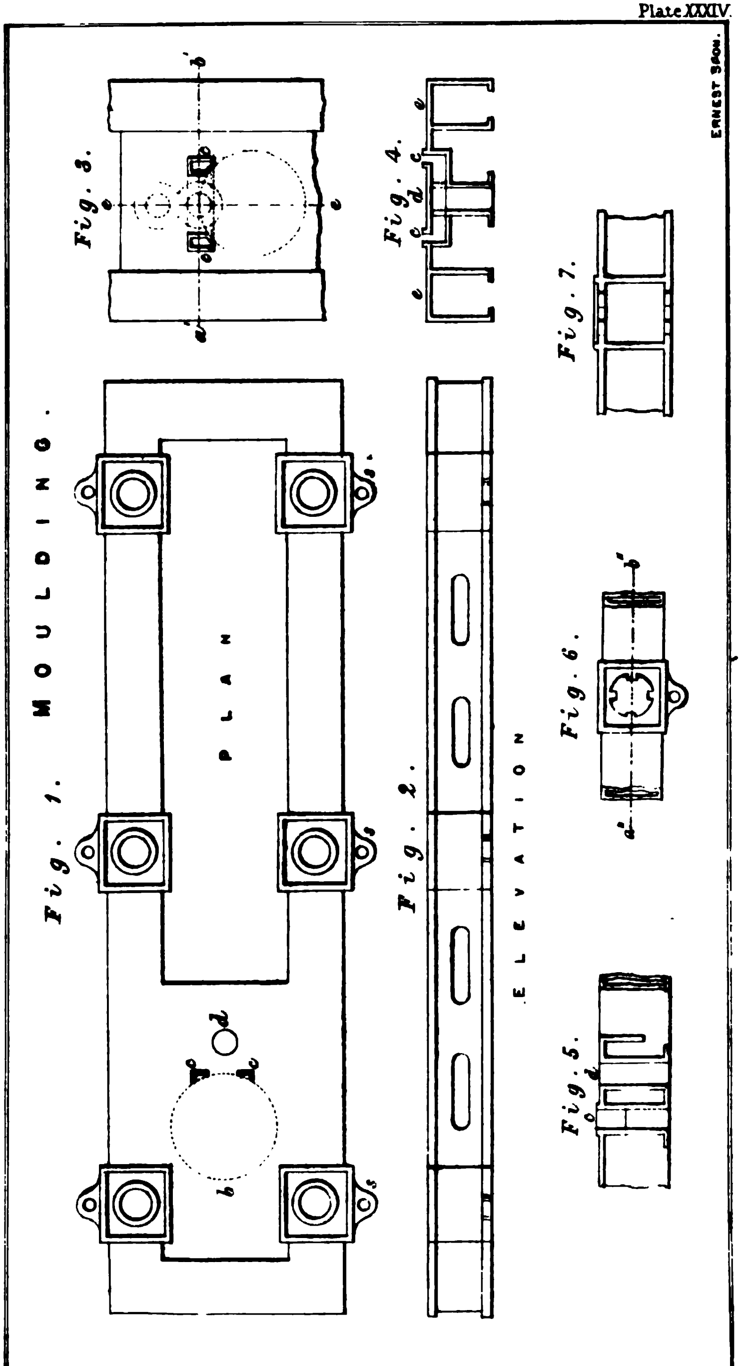

E & F N Spon, London & New York

MOULDING.

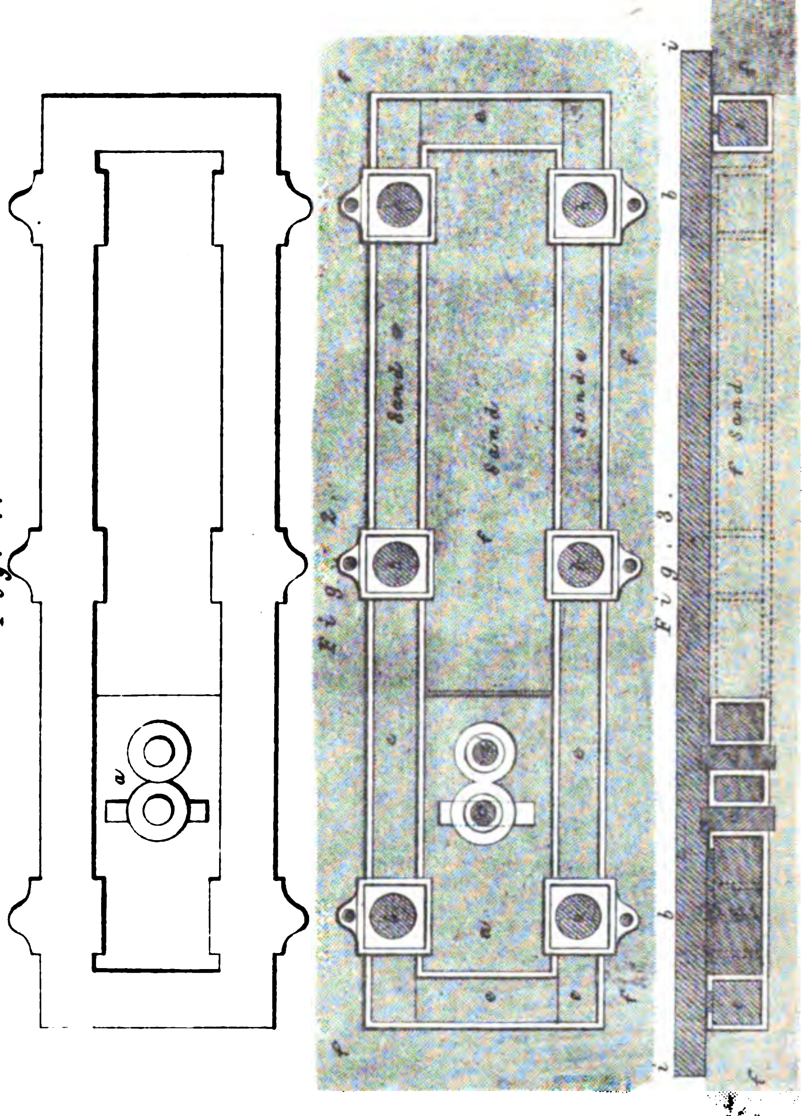

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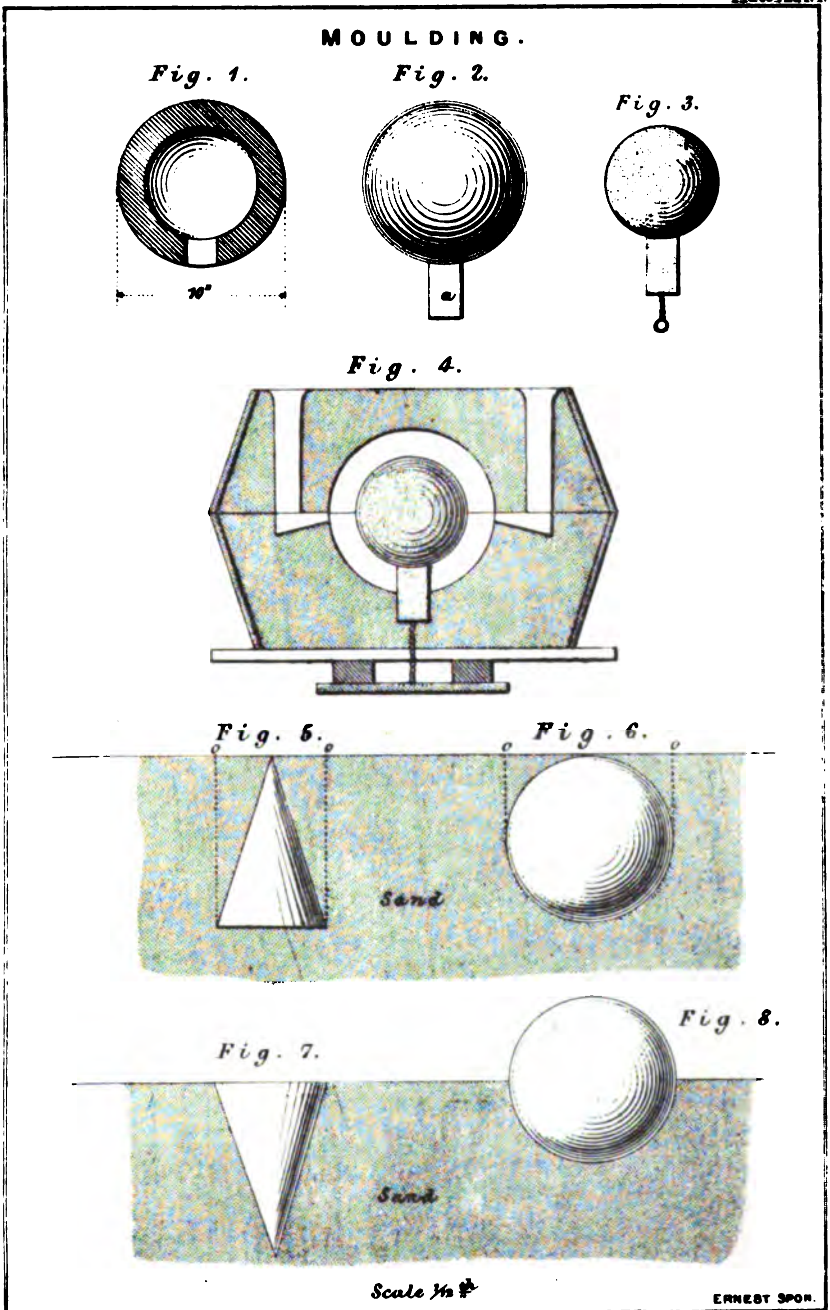
Plate XXXVI.



E. & F. N. Spon, London & New York.

MOULDING.

Fig. 1.

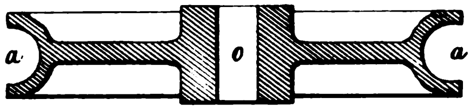


Fig. 2.

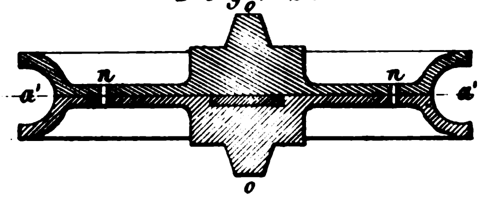


Fig. 3.

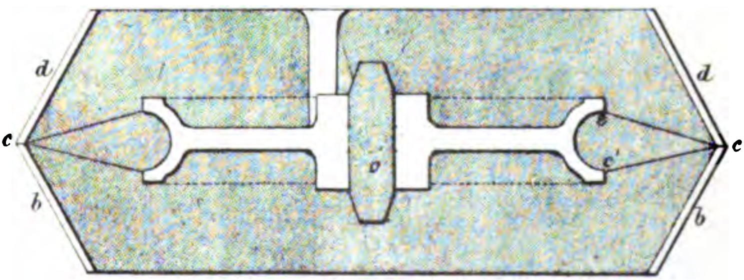


Fig. 4.

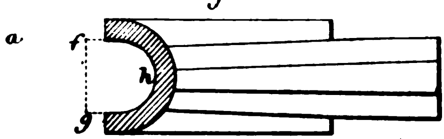


Fig. 5

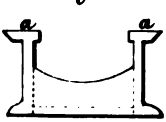
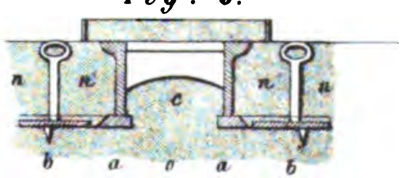


Fig. 6.



ERNEST SPON.

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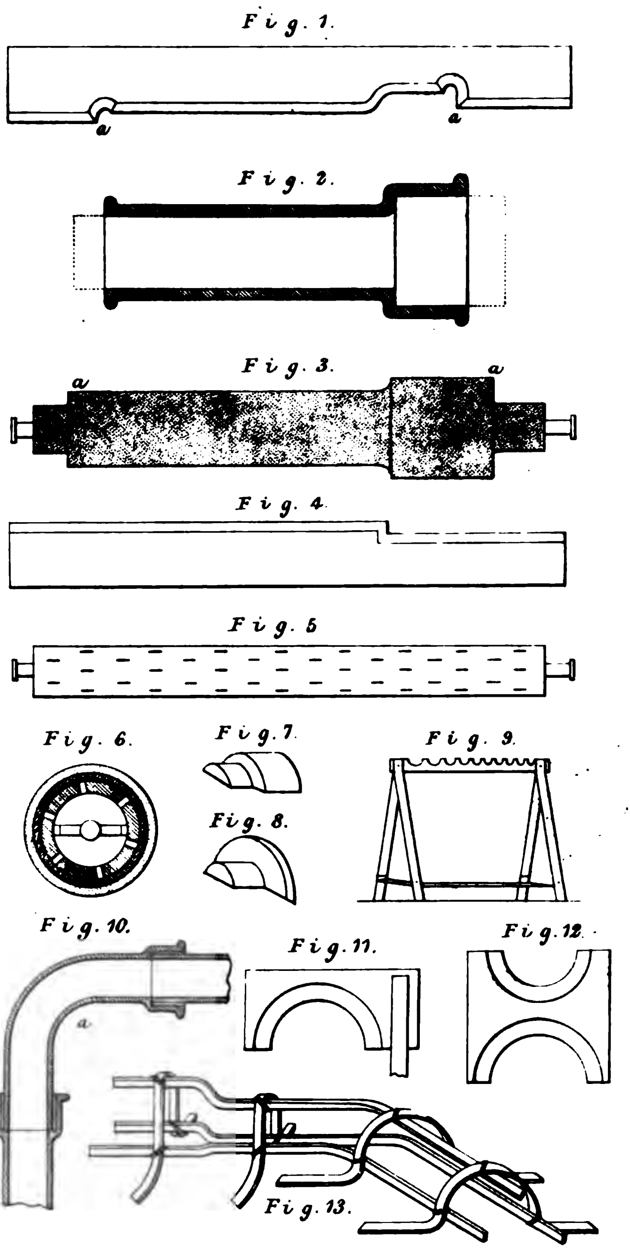
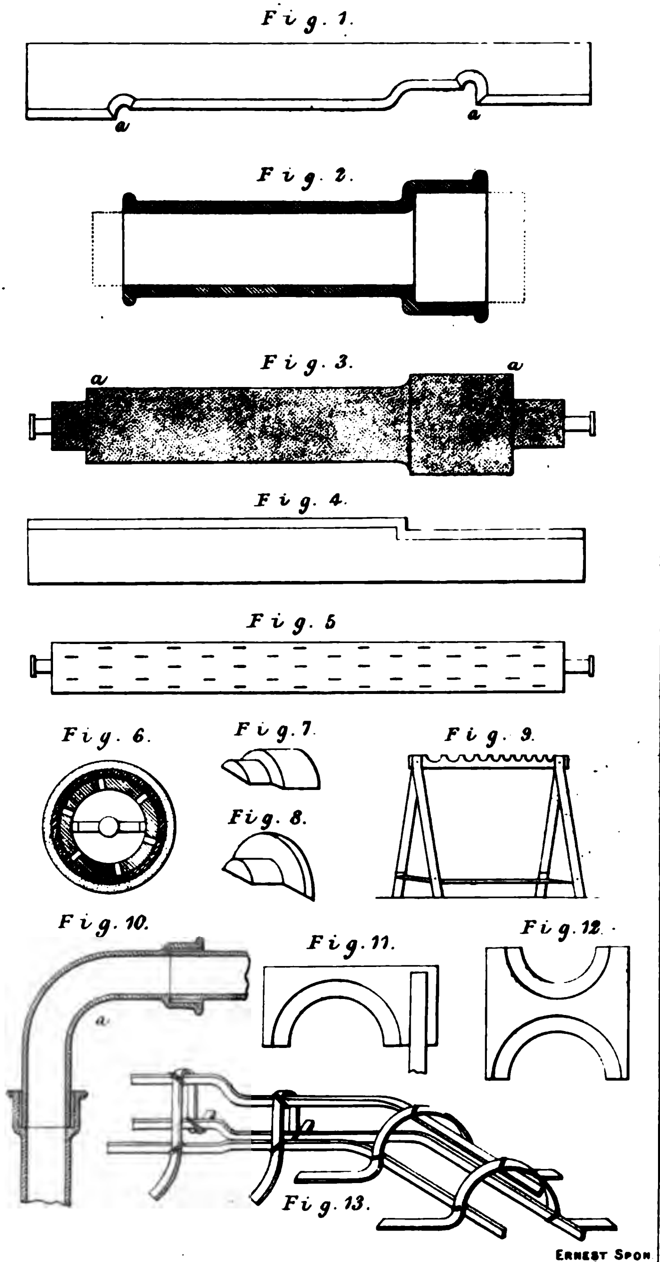
MOULDING.



E&F N. Spon, London & New York.

MOULDING.



ERNEST SPON

E&F N Spon, London & New York.

MOULDING APPARATUS.

Fig 1
Side Elevation

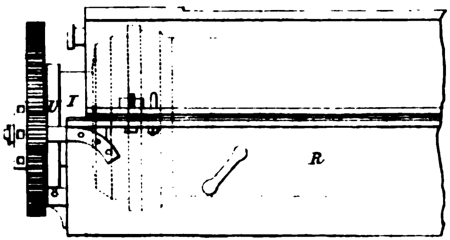


Fig . 2
Longitudinal Section

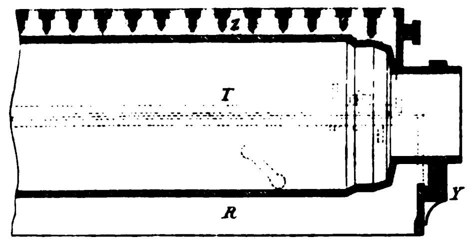


Fig 3.
Front Elevation

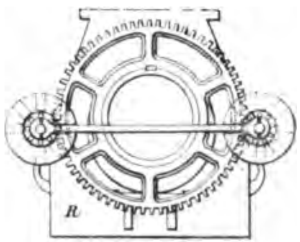


Fig 4
Back Elevation with flask in Section

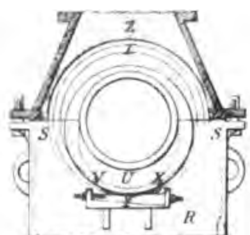
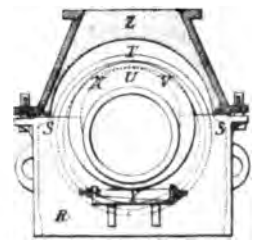


Fig 5.



Scale 1/36 th
Ins 12 6 0 1 2 3 4 5 6 Feet

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JOBSON'S MOULDING MACHINE.

Fig. 1

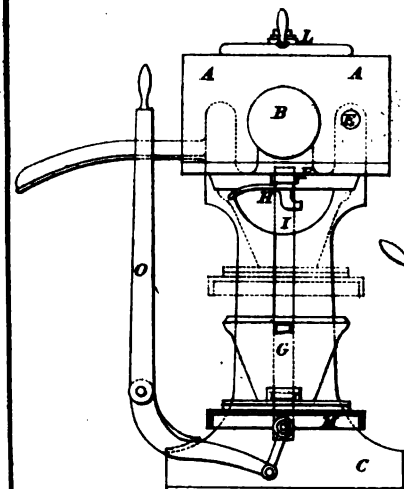


Fig. 2

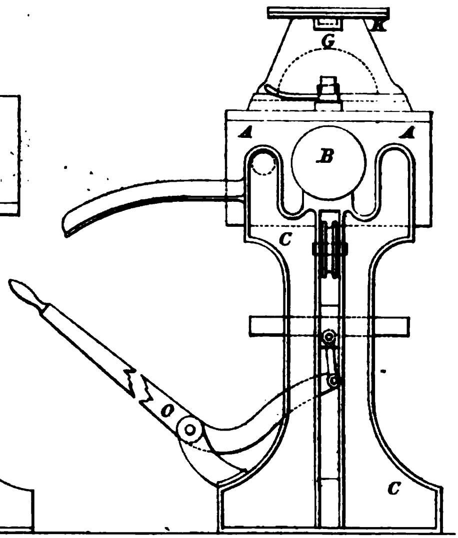
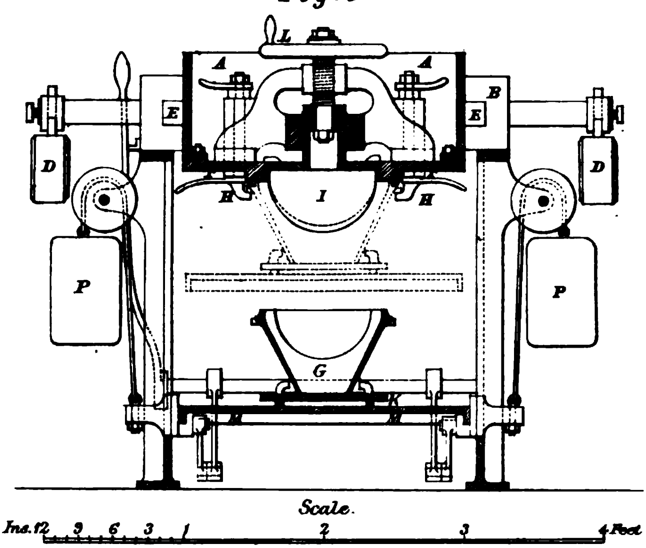


Fig. 3



ERNEST. SPON.

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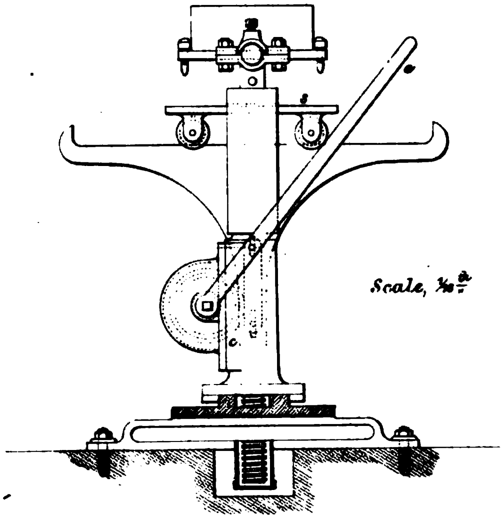
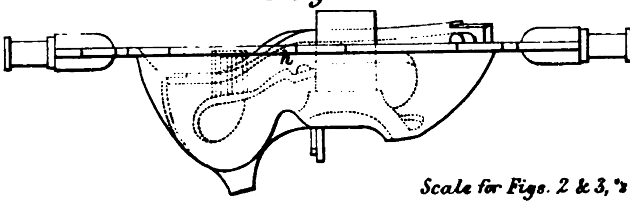
Fig. 1.



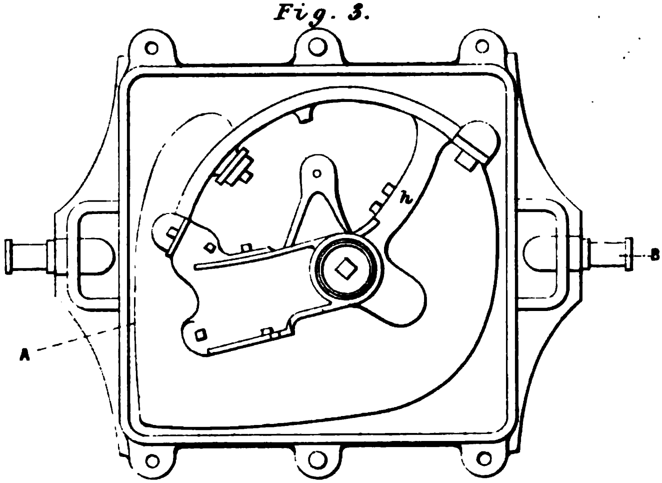
Scale, 1/10th.

Fig. 2.



Scale for Figs. 2 & 3, 1/8th.

Fig. 3.



ERNEST SPON.

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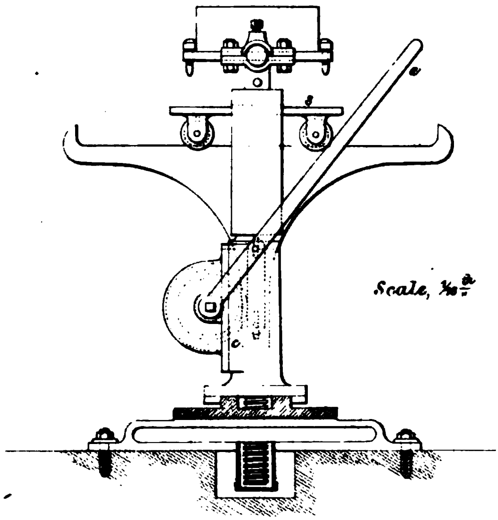
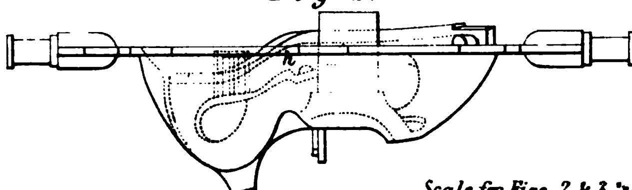
Fig. 1.



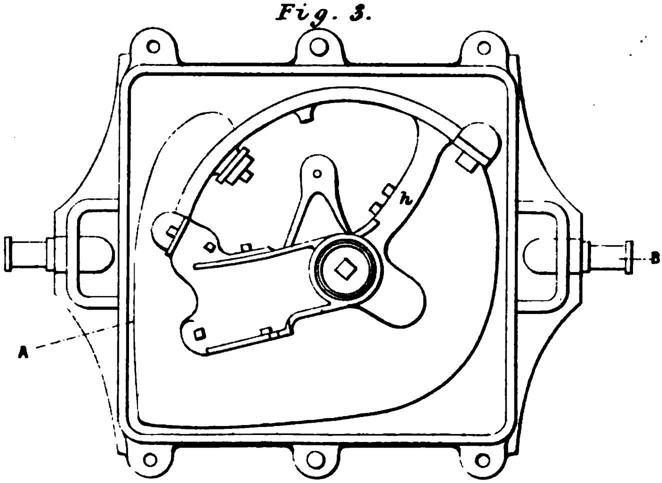
Scale, 1/10th

Fig. 2.



Scale for Figs. 2 & 3, 1/3th

Fig. 3.



ERNEST SPON.

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Plate XLIV.

Fig. 1

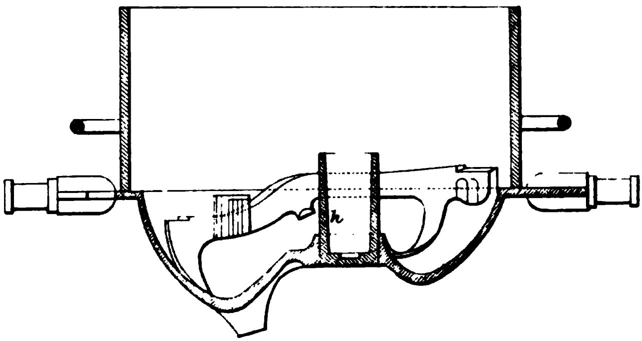


Fig. 2

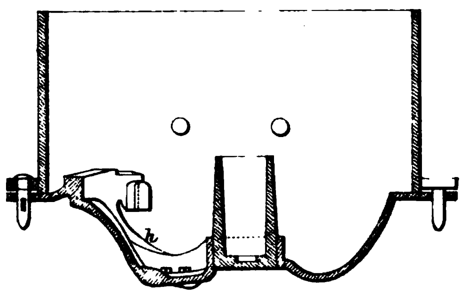


Fig. 3.

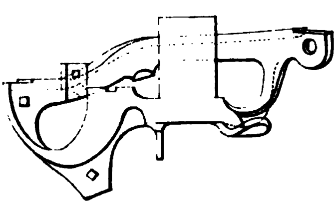
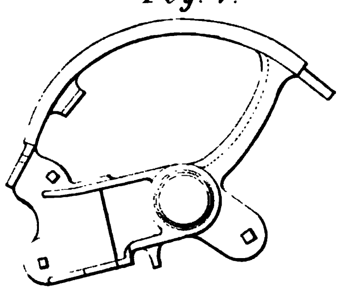


Fig. 4.



ERNEST SPON.

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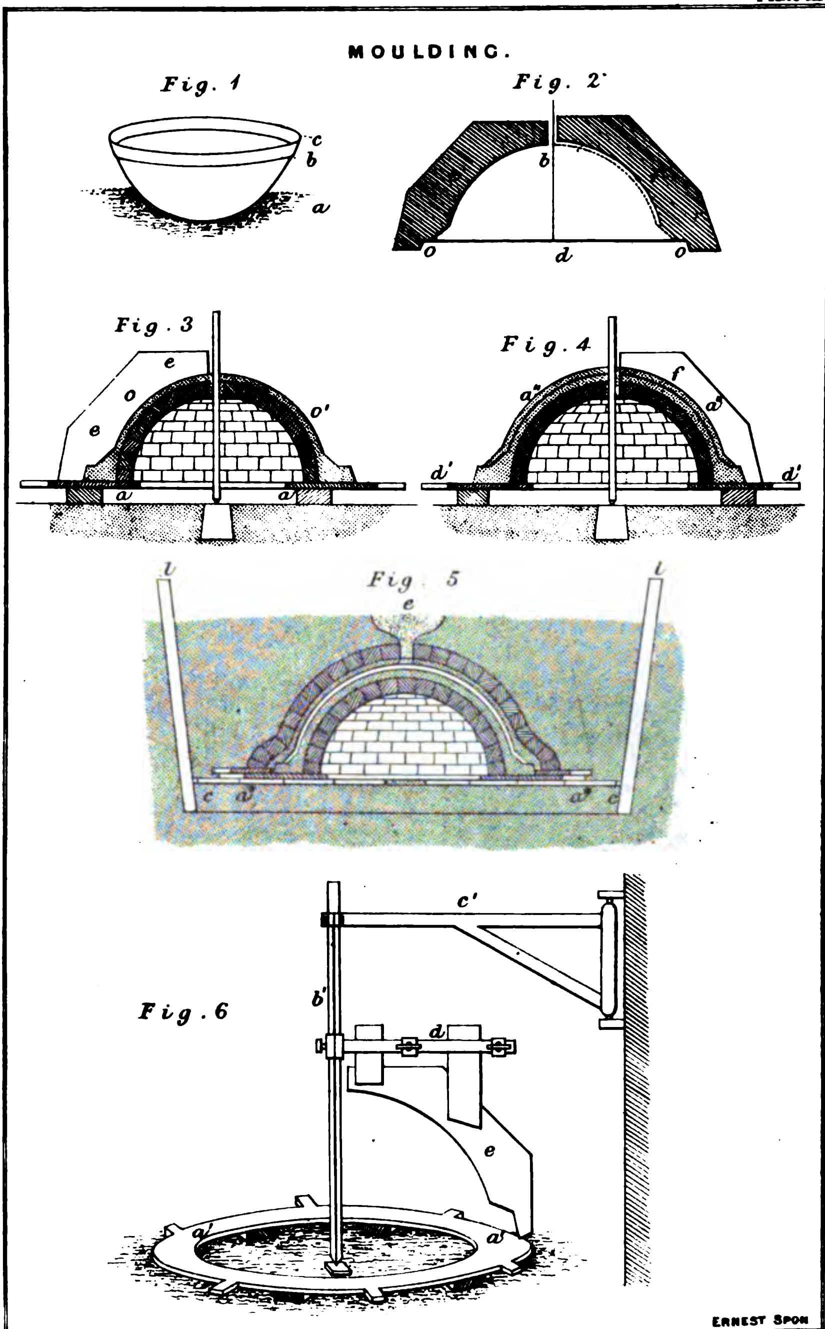


E & F N. Spon London & New York.

MOULDING

Fig. 1

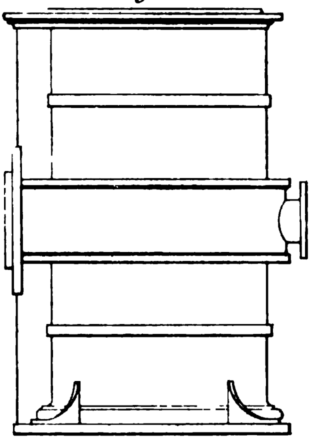


Fig. 2

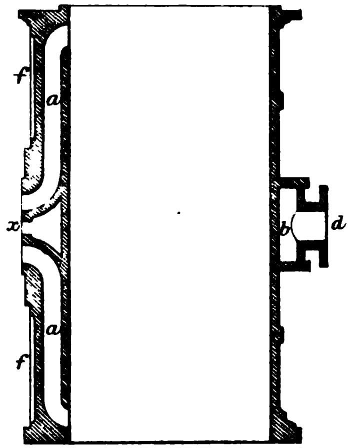


Fig. 4

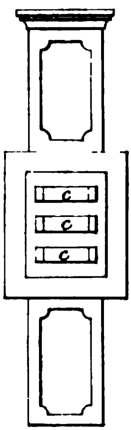


Fig. 5

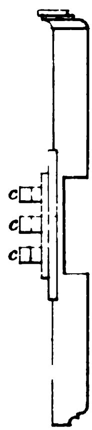


Fig. 3

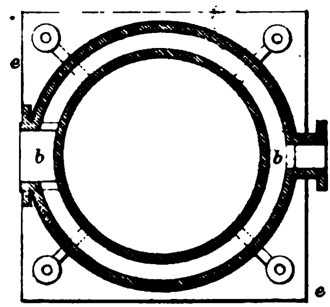
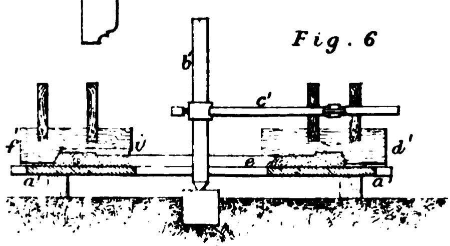


Fig. 6



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MOULDING.

Fig. 1

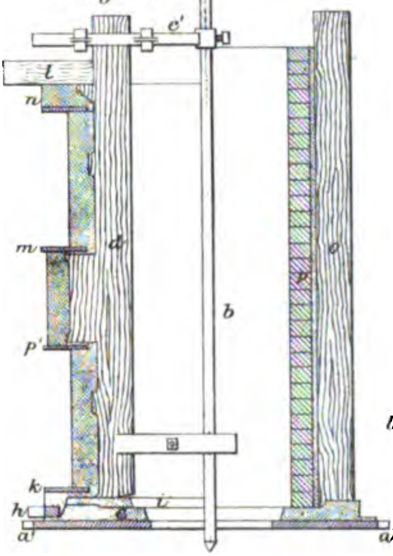

Fig. 2

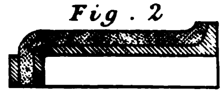

Fig. 3

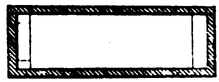

Fig. 4

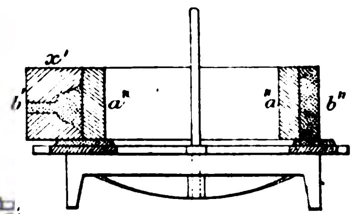

Fig. 5

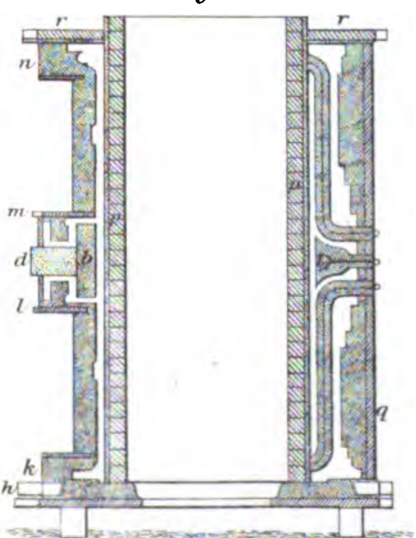

Fig. 6

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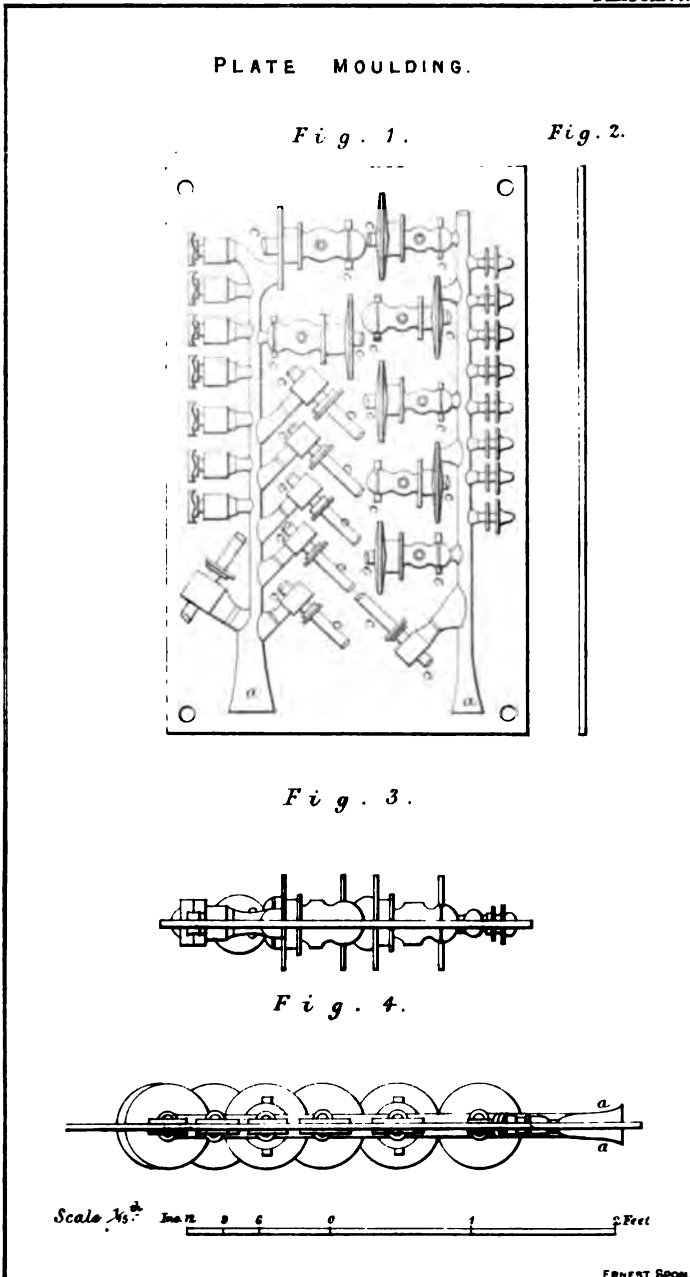

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CHILL MOULDS.

Fig. 1.

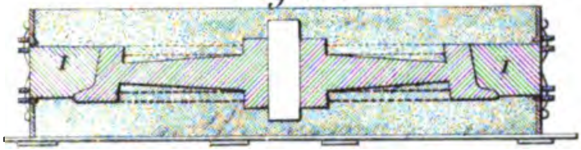
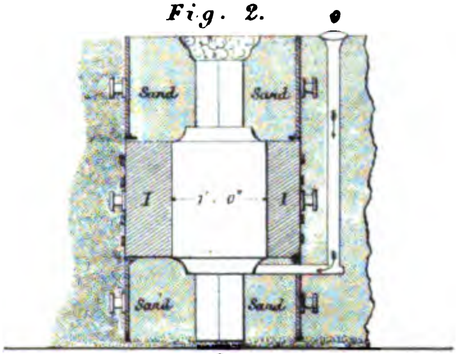


Fig. 2.



Scale; Figs. 3 to 7, 1/6th. Fig. 1, 1/12th. Fig. 2, 1/24th.

Fig. 3.

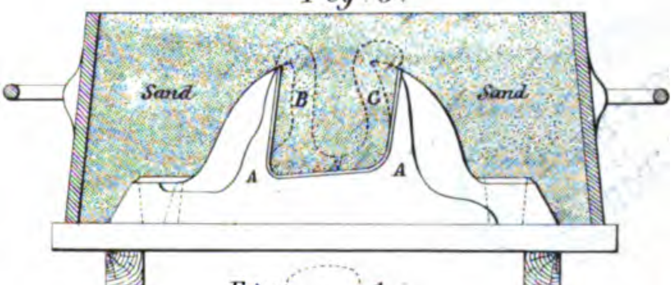


Fig. 4.

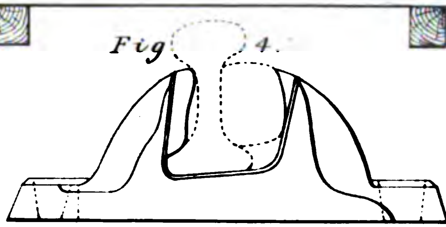
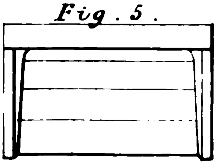


Fig. 5.



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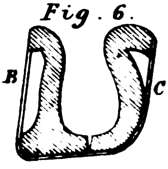
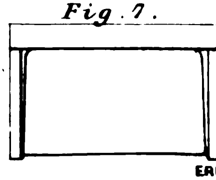


Fig. 7.

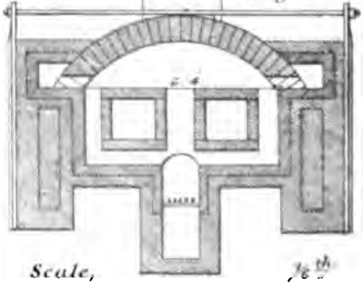


ERNEST SPON.

E & F.N. Spon. London & New York.

DODD'S CASE HARDENING FURNACE.

Fig. 1



Scale, 1/16th

Fig. 2

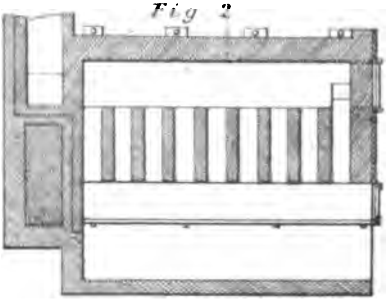


Fig. 3

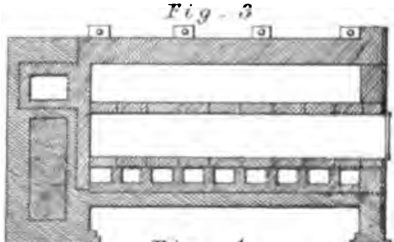
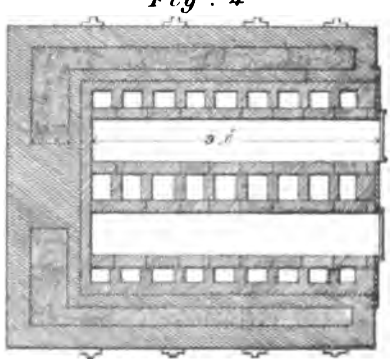


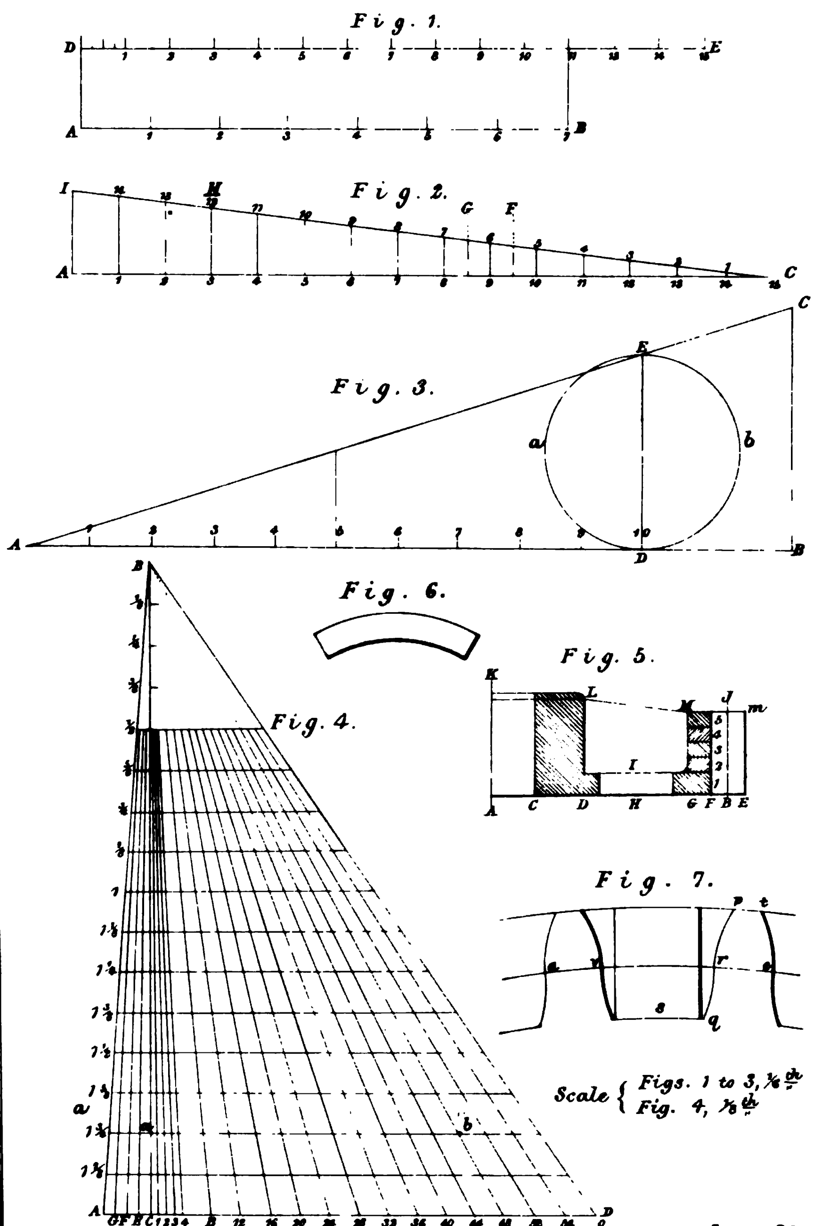
Fig. 4



ERNEST SPON

E & F N Spon London & New York

WHEEL MOULDING.



ERNEST SPON.

E. & F. N. Spon, London & New York

WHEEL MOULDING.

Fig. 1.

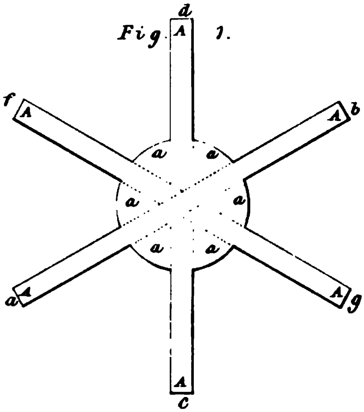


Fig. 2.

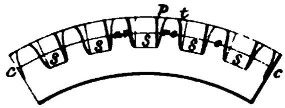


Fig. 3.

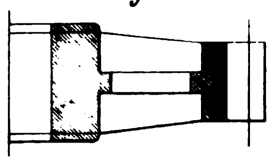


Fig. 5a.

Fig. 5.

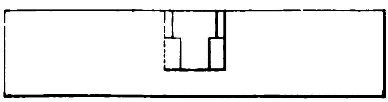


Fig. 6.

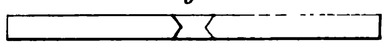


Fig. 7

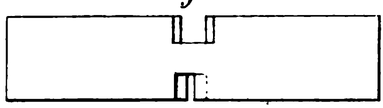


Fig. 8.

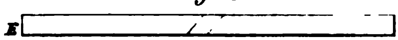
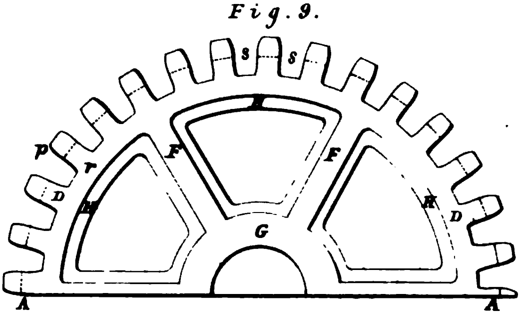


Fig. 9.



Ernest Spon.

E & F N. Spon, London & New York

WHEEL MOULDING.

Fig. 1.

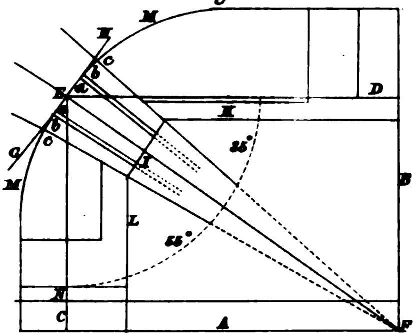


Fig. 2.

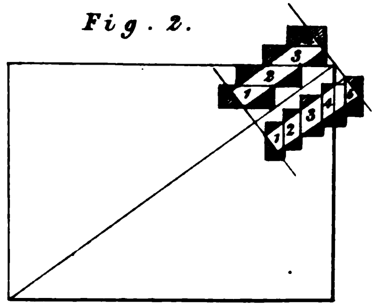


Fig. 3.

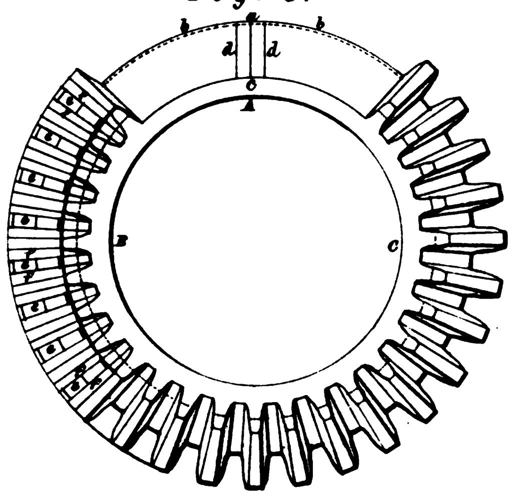
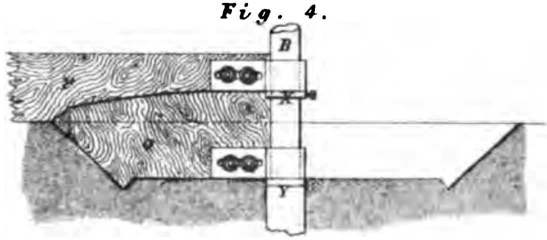


Fig. 4.



ERNEST SPON.

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WHEEL MOULDING MACHINE.

Fig. 1.

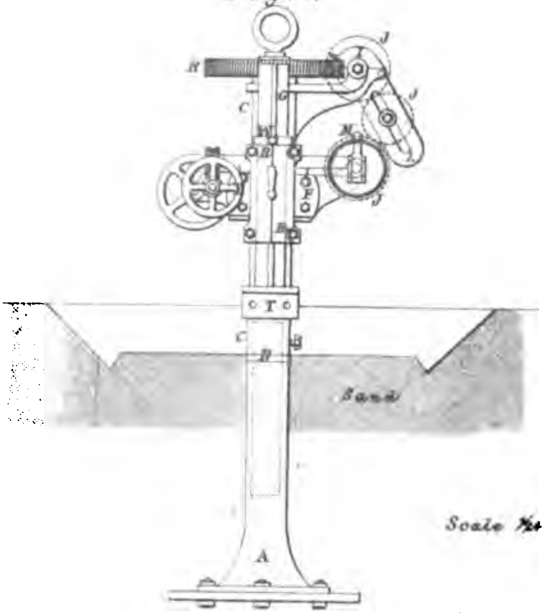


Fig. 2.

Scale 1/24th

Fig. 3.

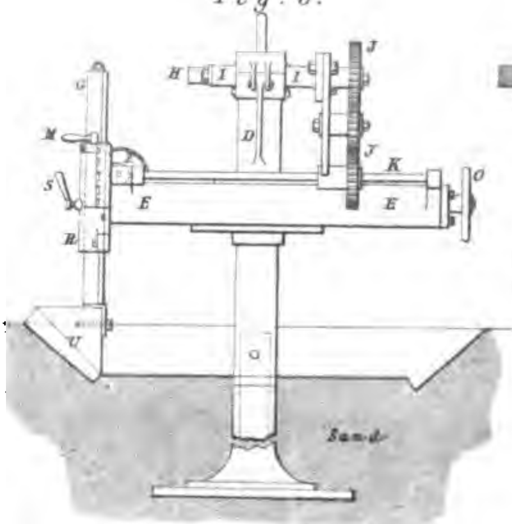
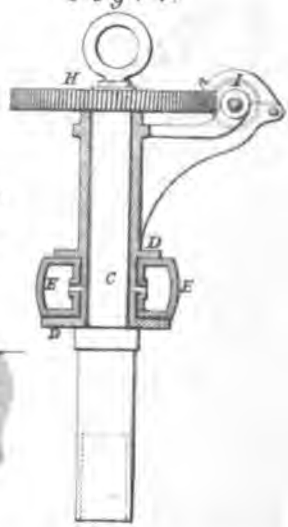


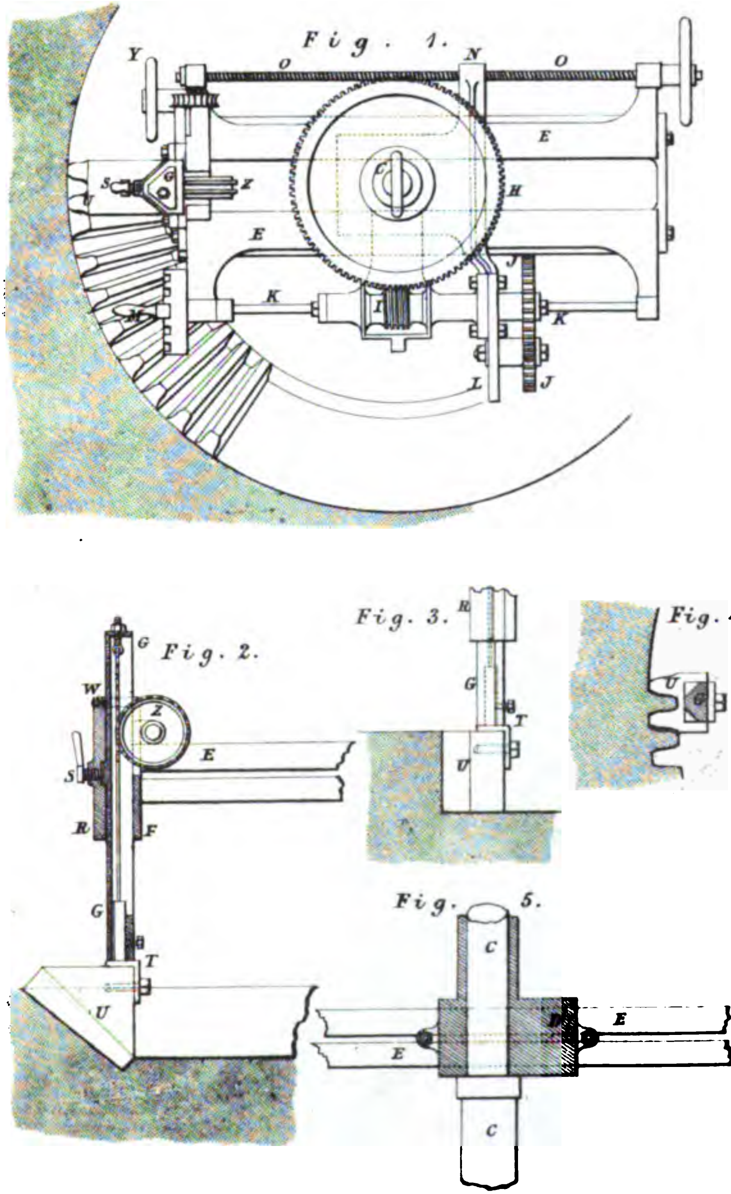
Fig. 4.



ERNEST SPON

E. & F. N. Spon London & New York.

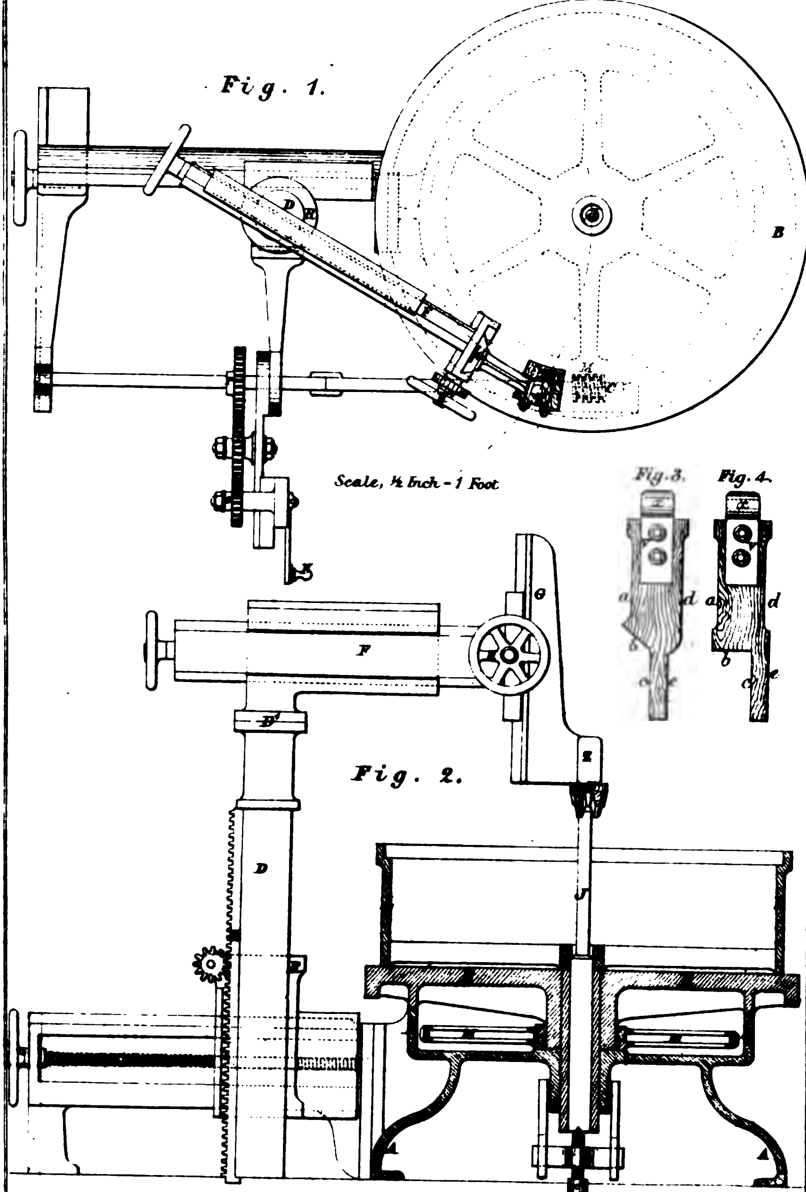
WHEEL MOULDING MACHINE.



ERNEST SPON

E. & F. N. Spon, London & New York.

WHEEL MOULDING MACHINE.

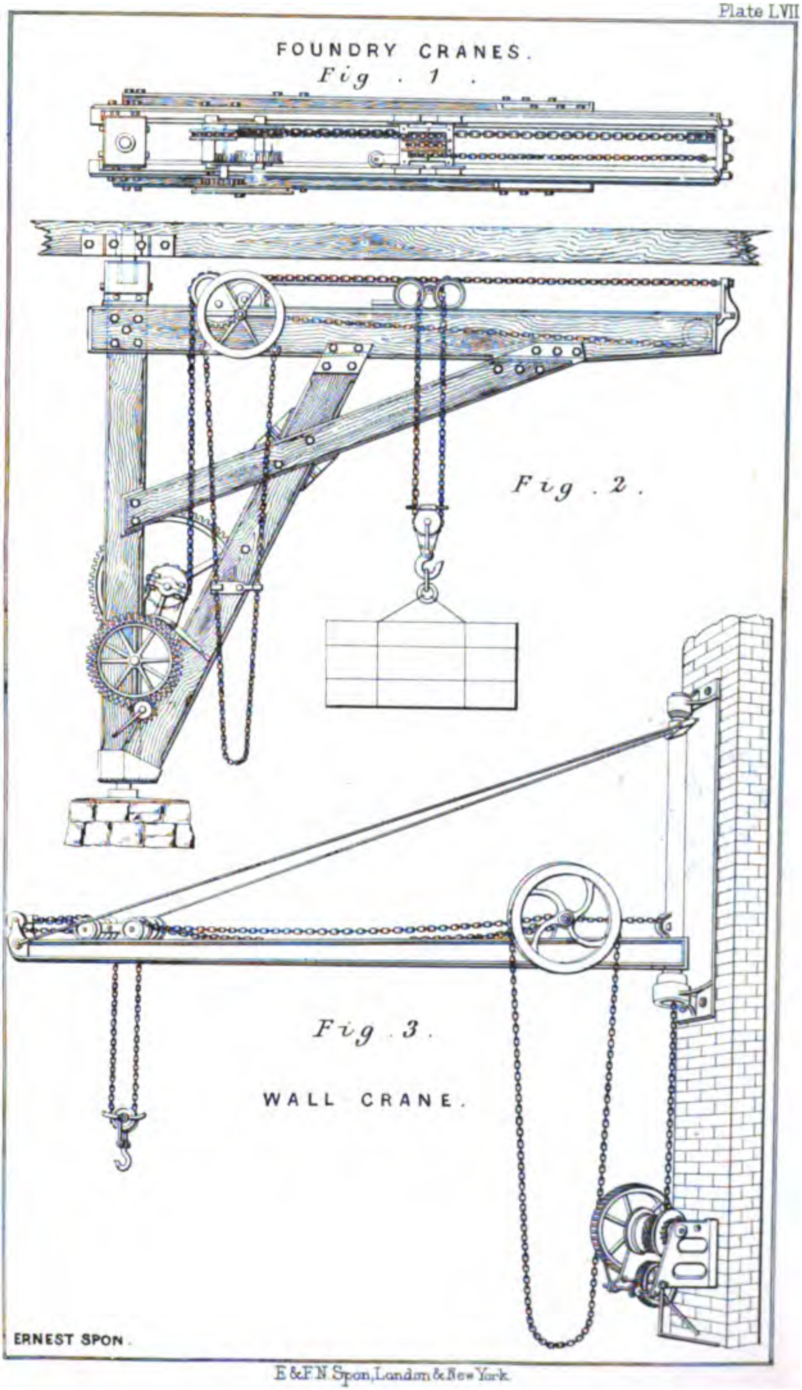


ERNEST SPON.

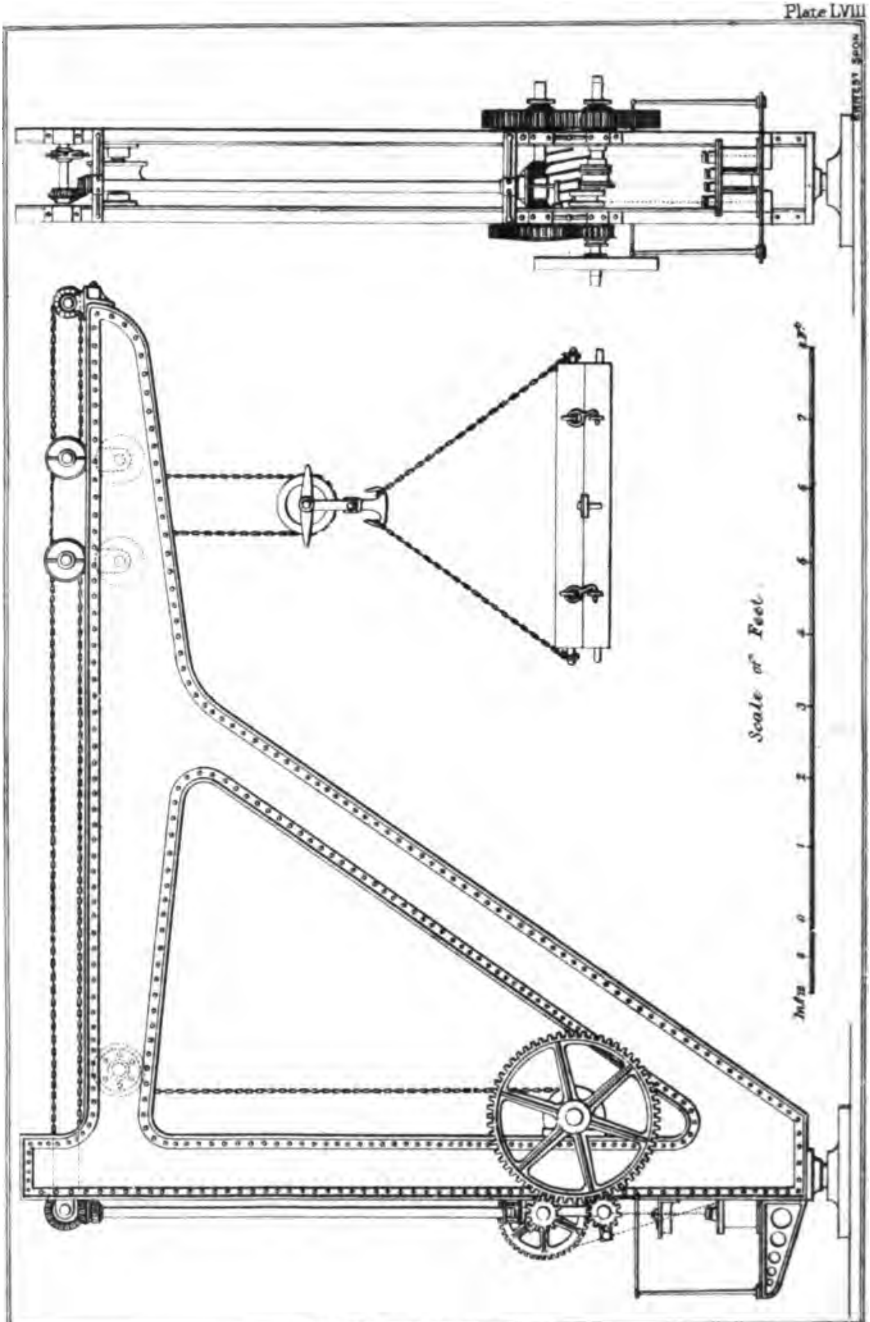
E.&F.N. Spon, London & New York

Plate LVII.

FOUNDRY CRANES.

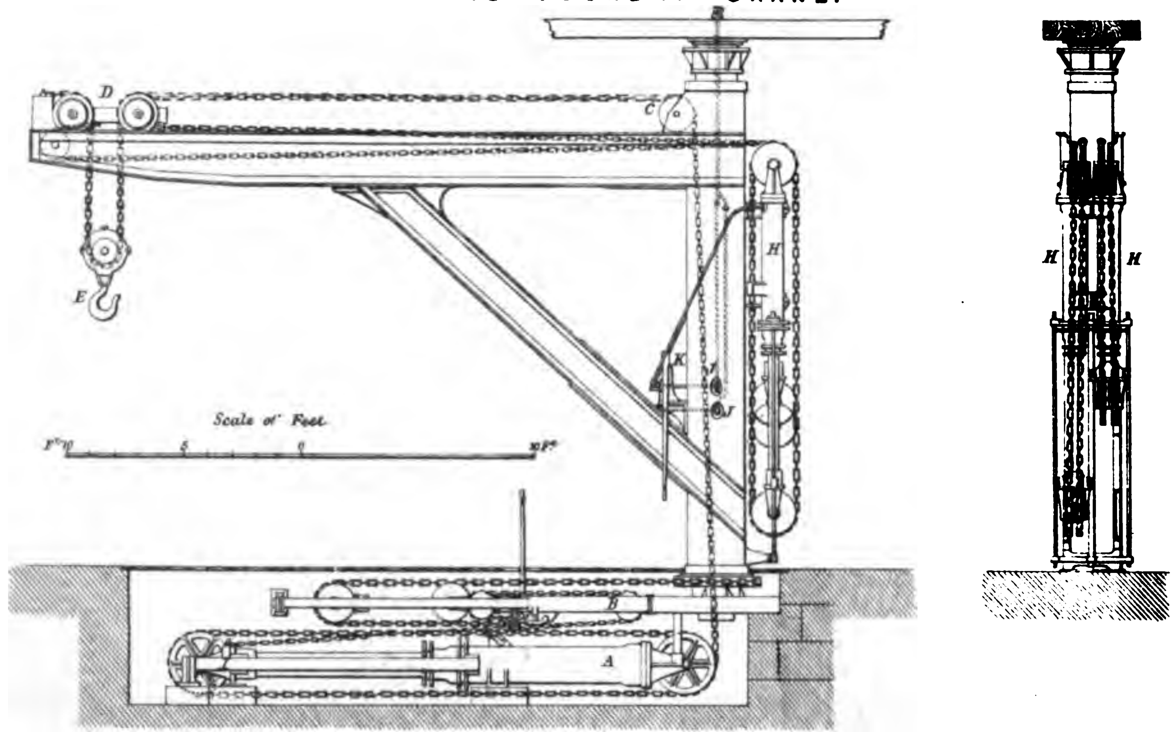


E.&F.N. Spon, London & New York.



E.&F.N. Spon, London & New York.

HYDRAULIC FOUNDRY CRANE.

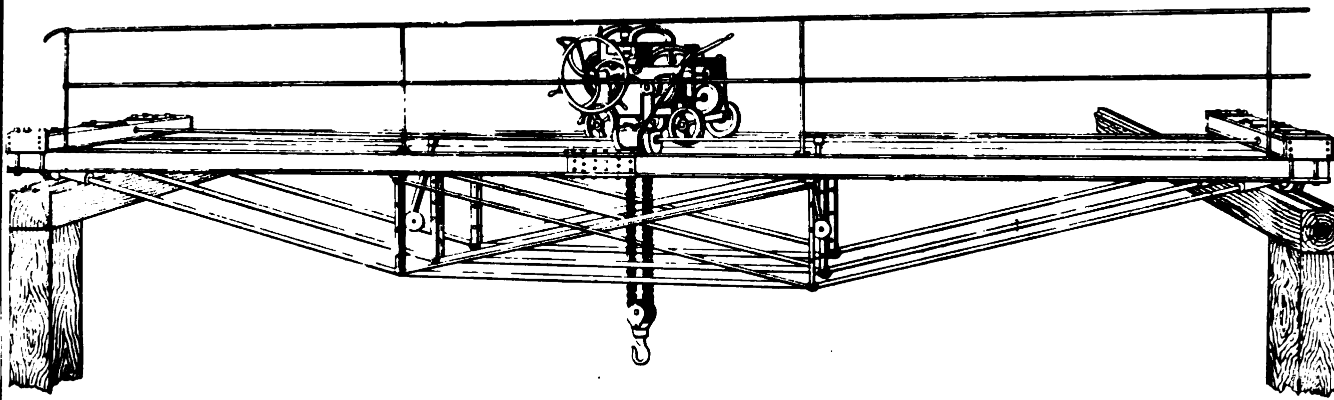


ERNEST SPON.

E & F. N. Spon, London & New York.

Plate LX.

APPLEBY'S OVERHEAD TRAVELLER.



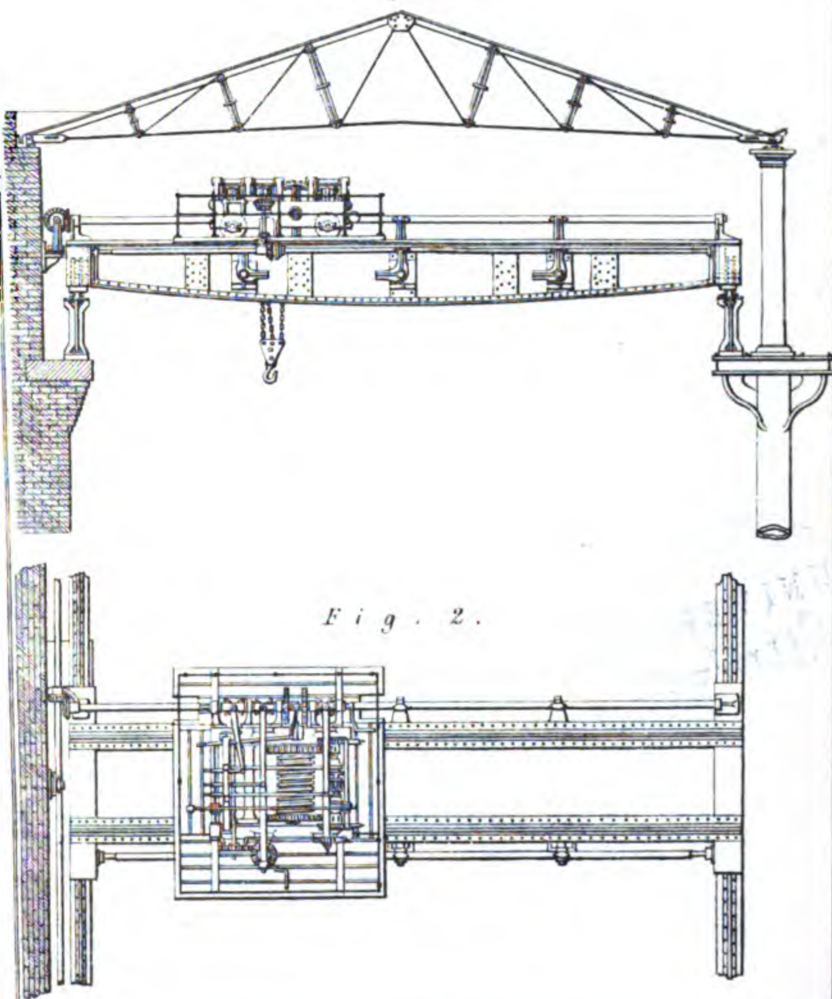
ERNEST SPON.

E. & F. N. Spon, London & New York.

APPLEBY'S CRANE.

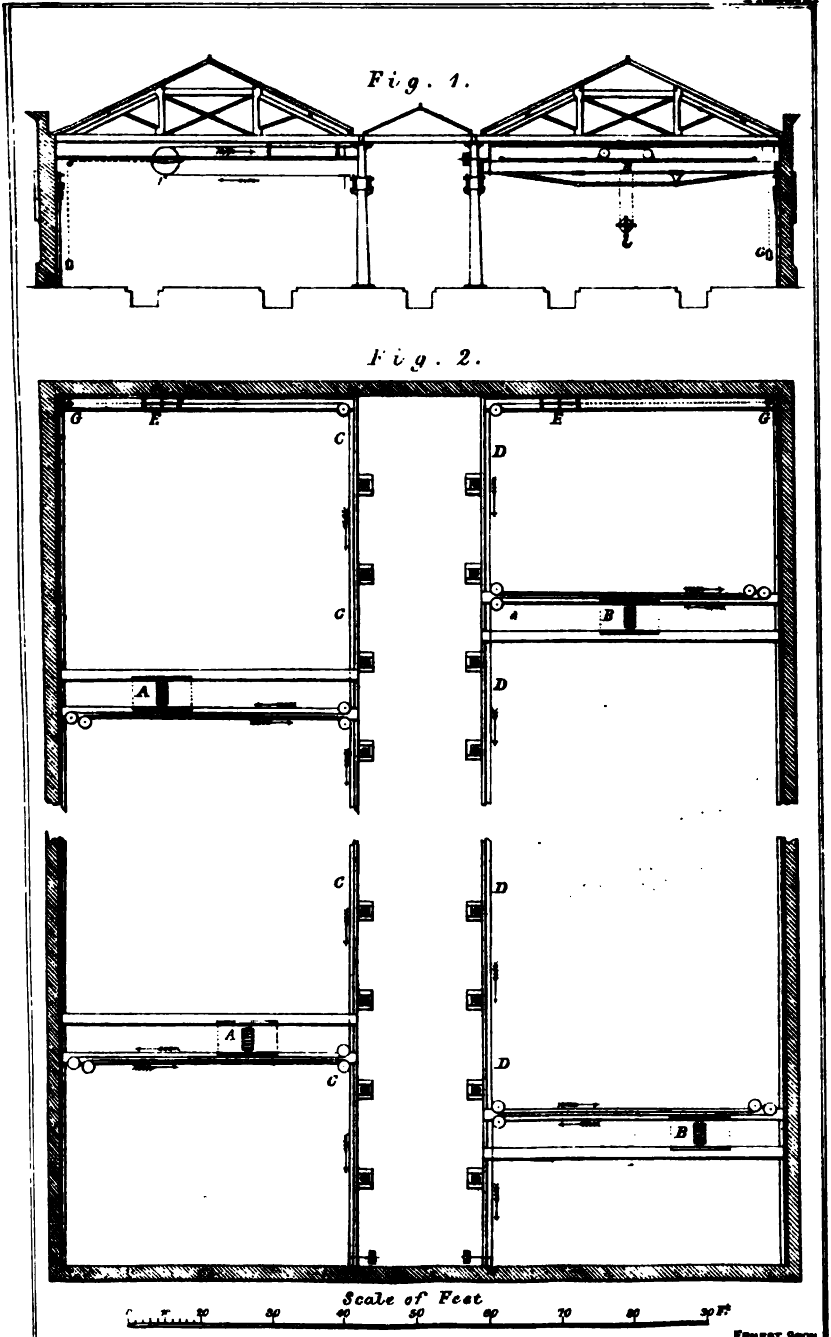
Fig. 1.

Fig. 2.



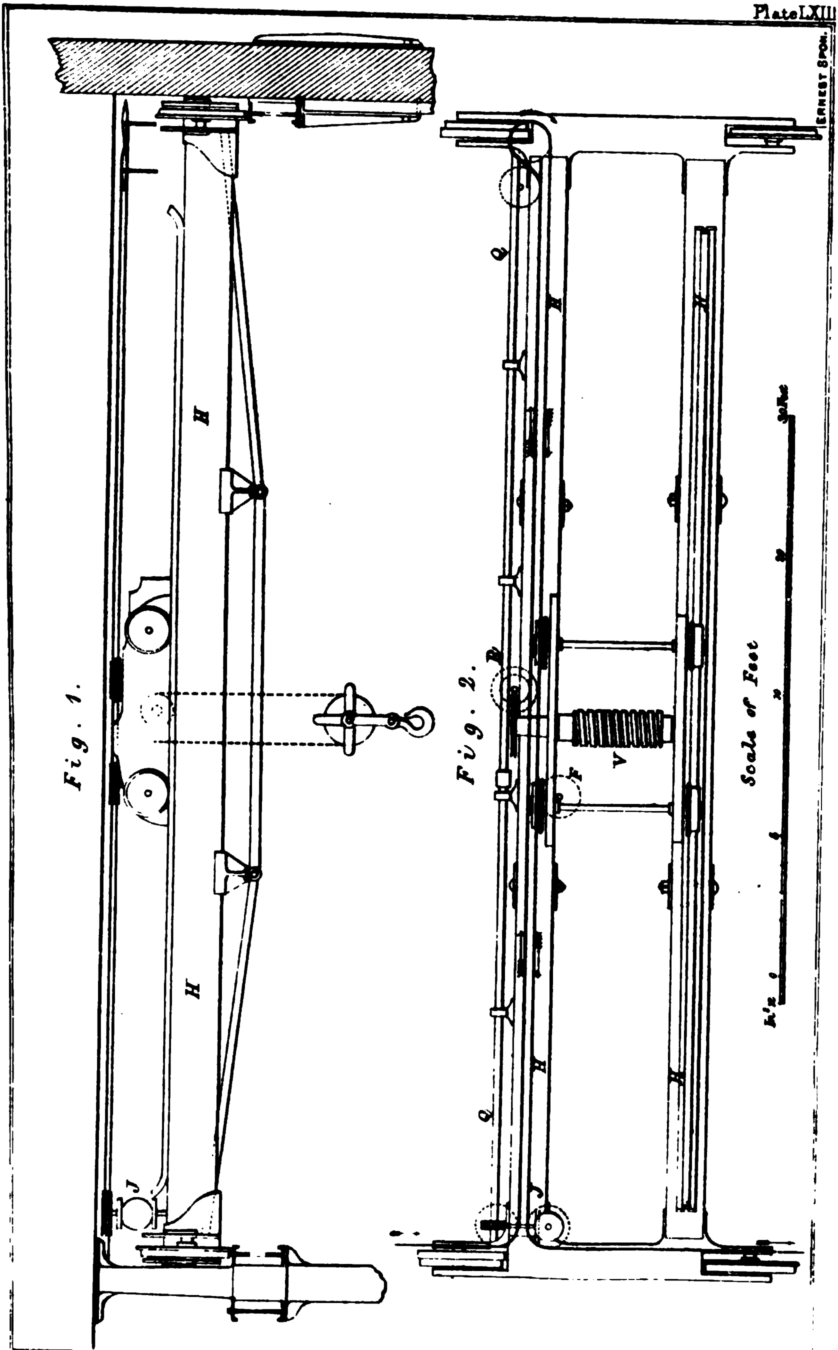
ERNEST SPON

E. & F. N. Spon, London & New York



E & F.N. Spon, London & New York

Plate LXIII



E. & F. N. Spon, London & New York.

Fig. 1.

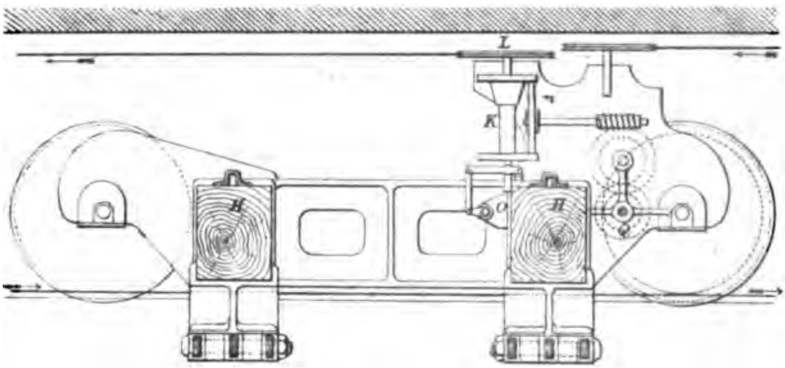


Fig. 2.

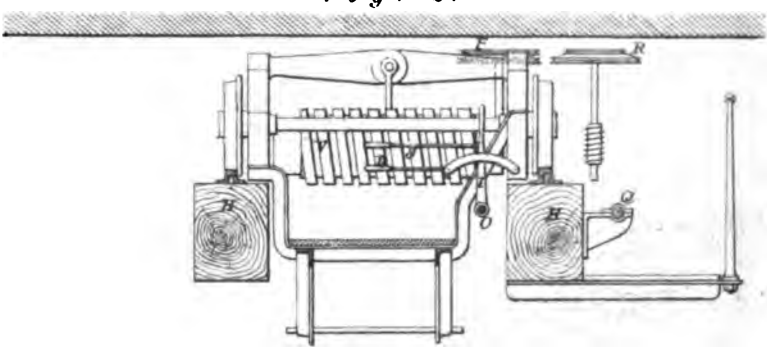
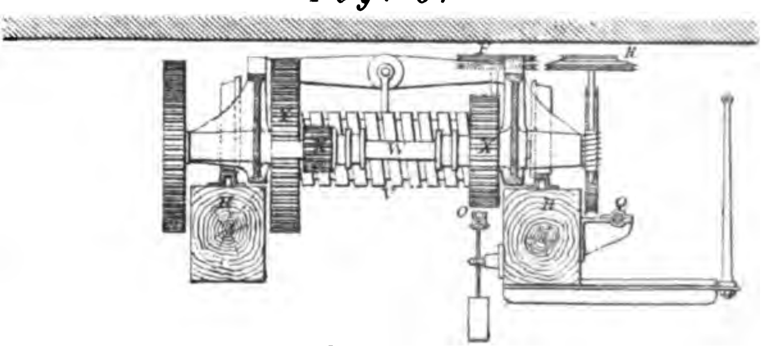


Fig. 3.



Scale of Feet

Ins 12 9 6 3 0 1 2 3 4 5 6 F

ERNEST SPON

E & F N Spon London, & New York.

OVERHEAD TRAVERSING CRANE.

Fig. 1.

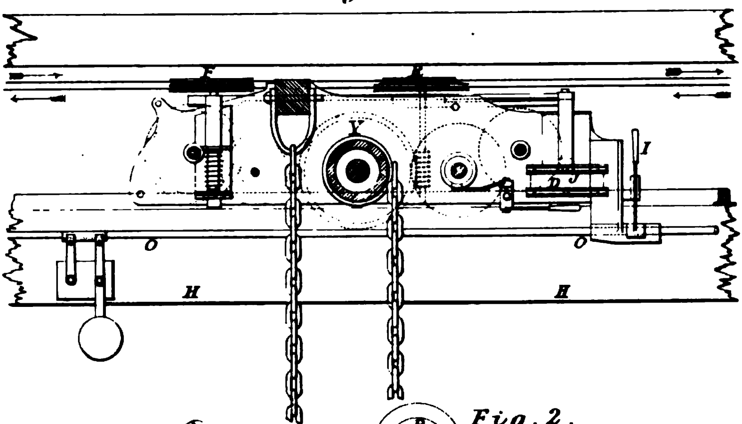


Fig. 2.

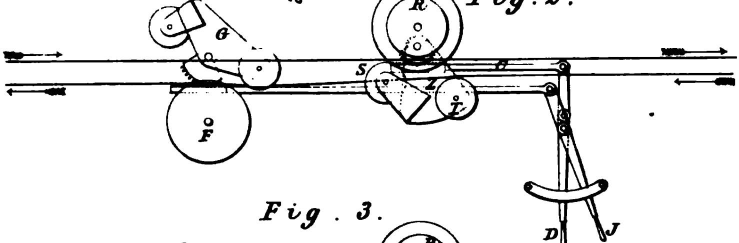
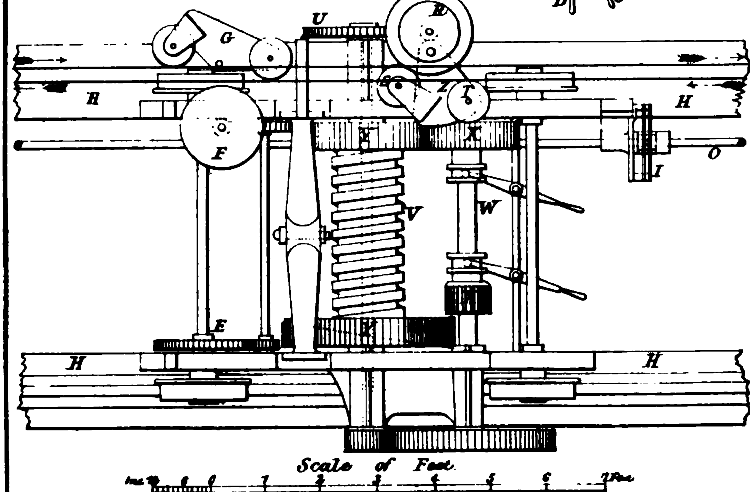


Fig. 3.

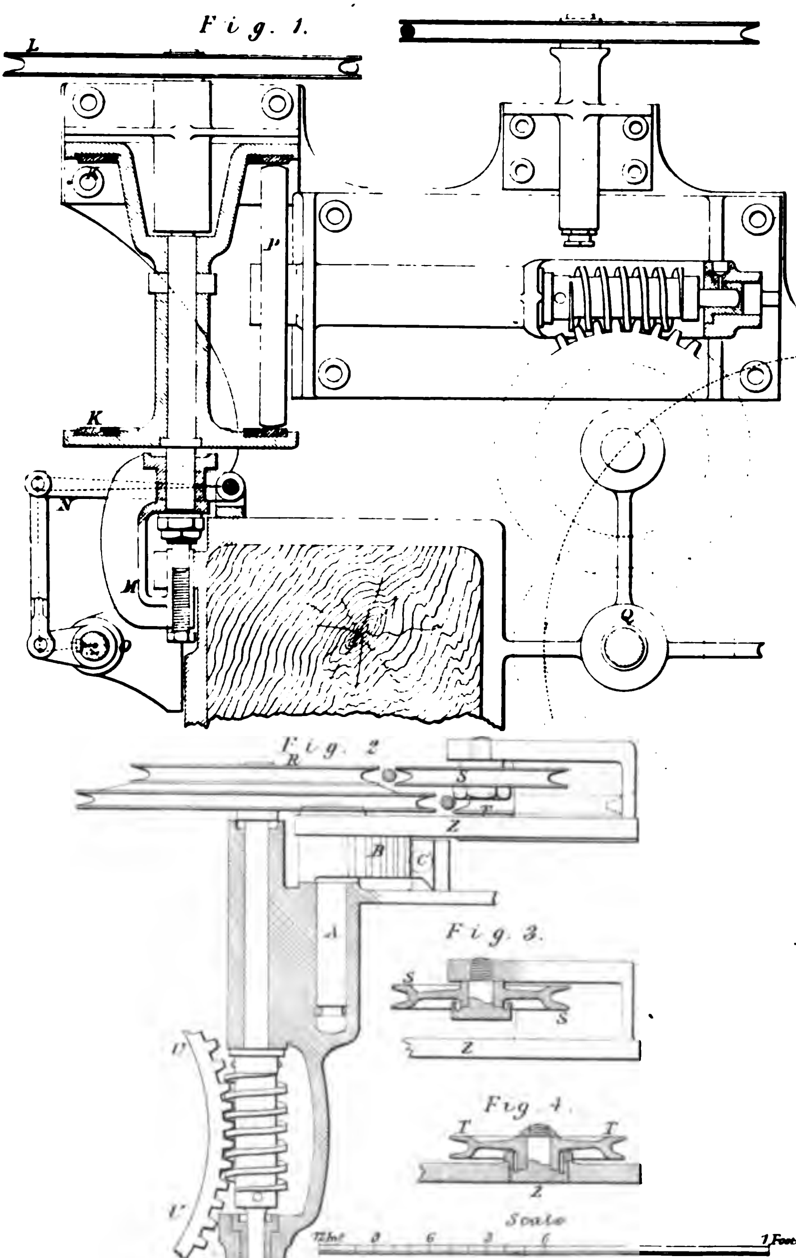


Scale of Feet.

ERNEST SPON.

E & F.N. Spon, London & New York

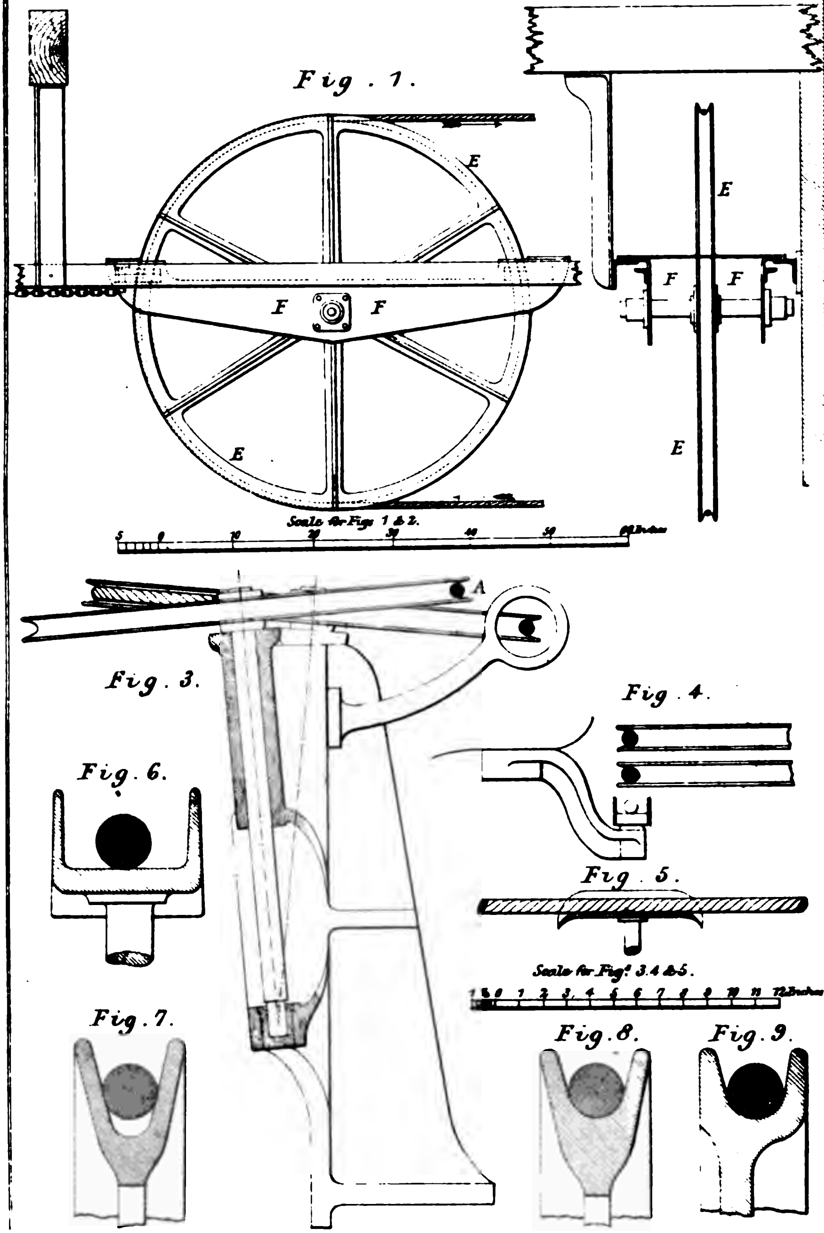
OVERHEAD TRAVERSING CRANE.



ERNEST SPON

E. & F. N. Spon, London & New York

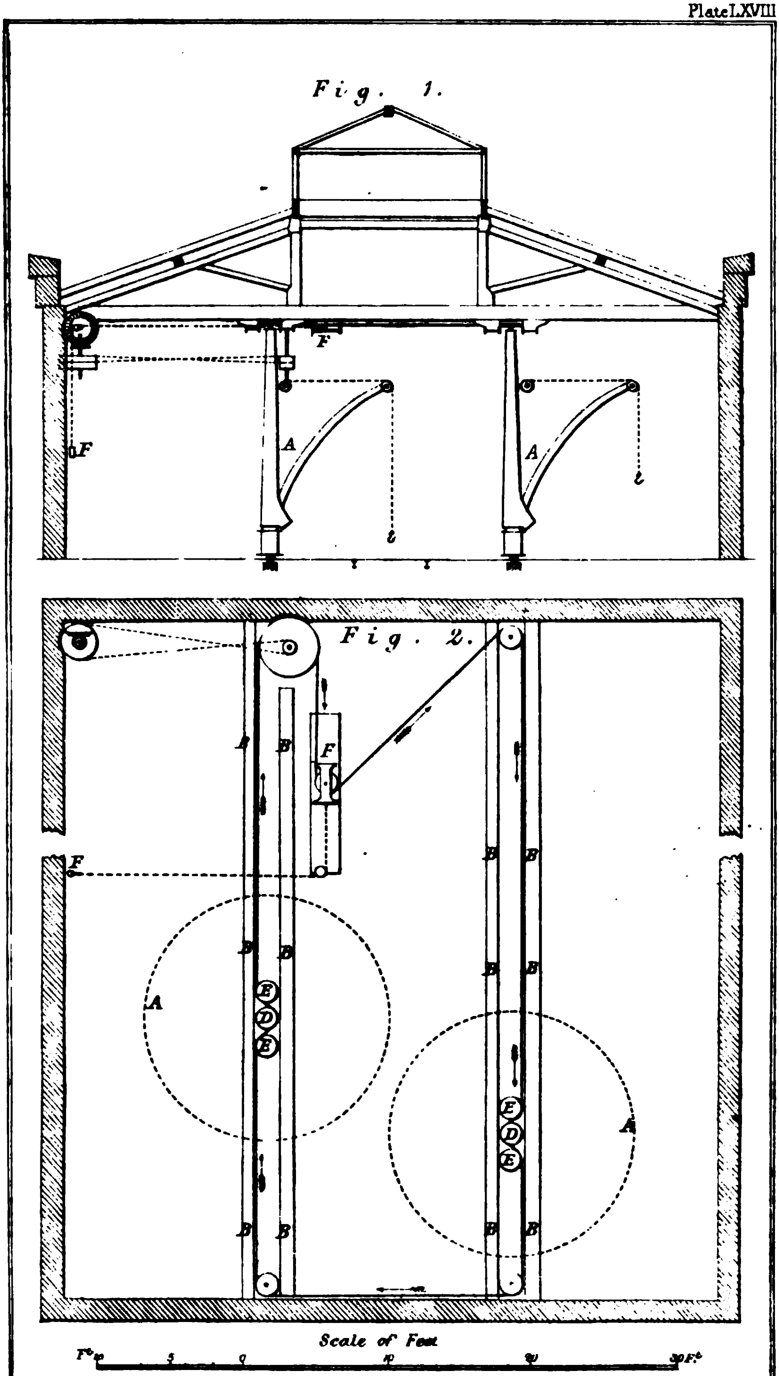
OVERHEAD TRAVERSING CRANE.



Scale, Figs. 6 to 9 — ½ full size

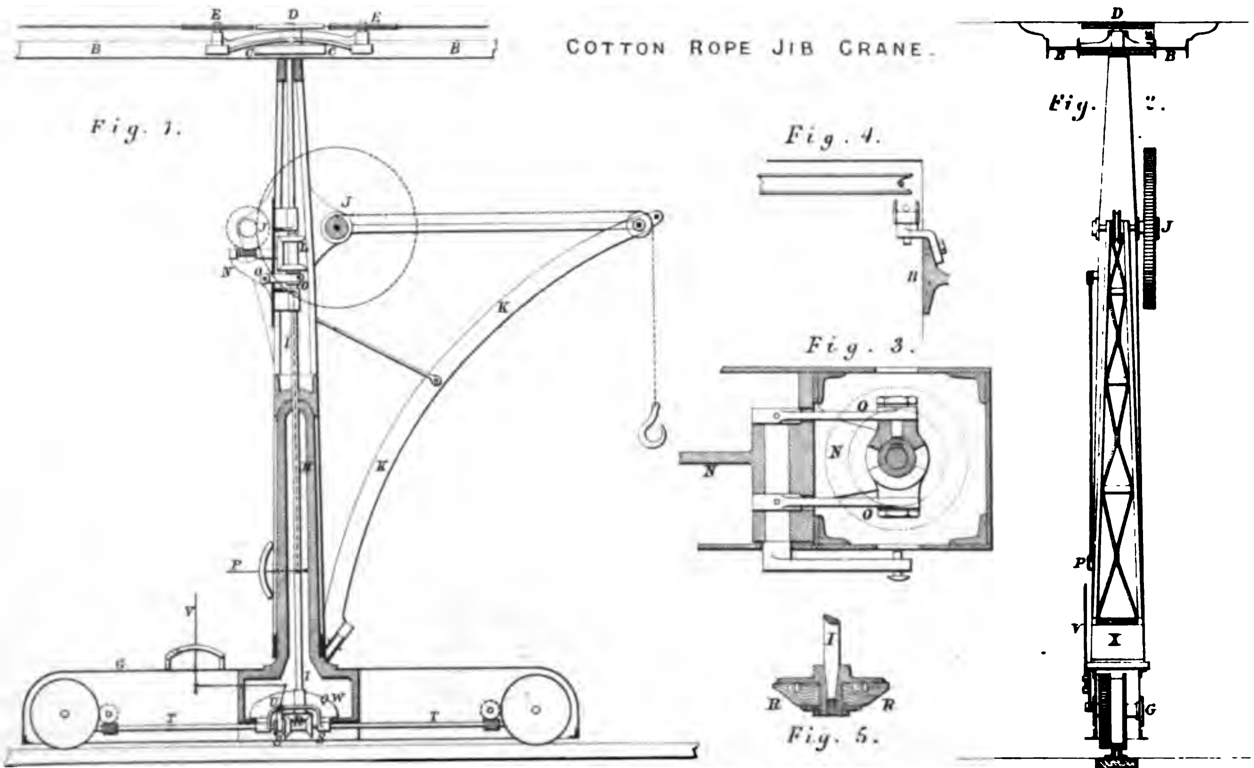
ERNEST SPON

E & F N Spon, London & New York.



E. & F. N. Spon, London & New York

COTTON ROPE JIB CRANE.



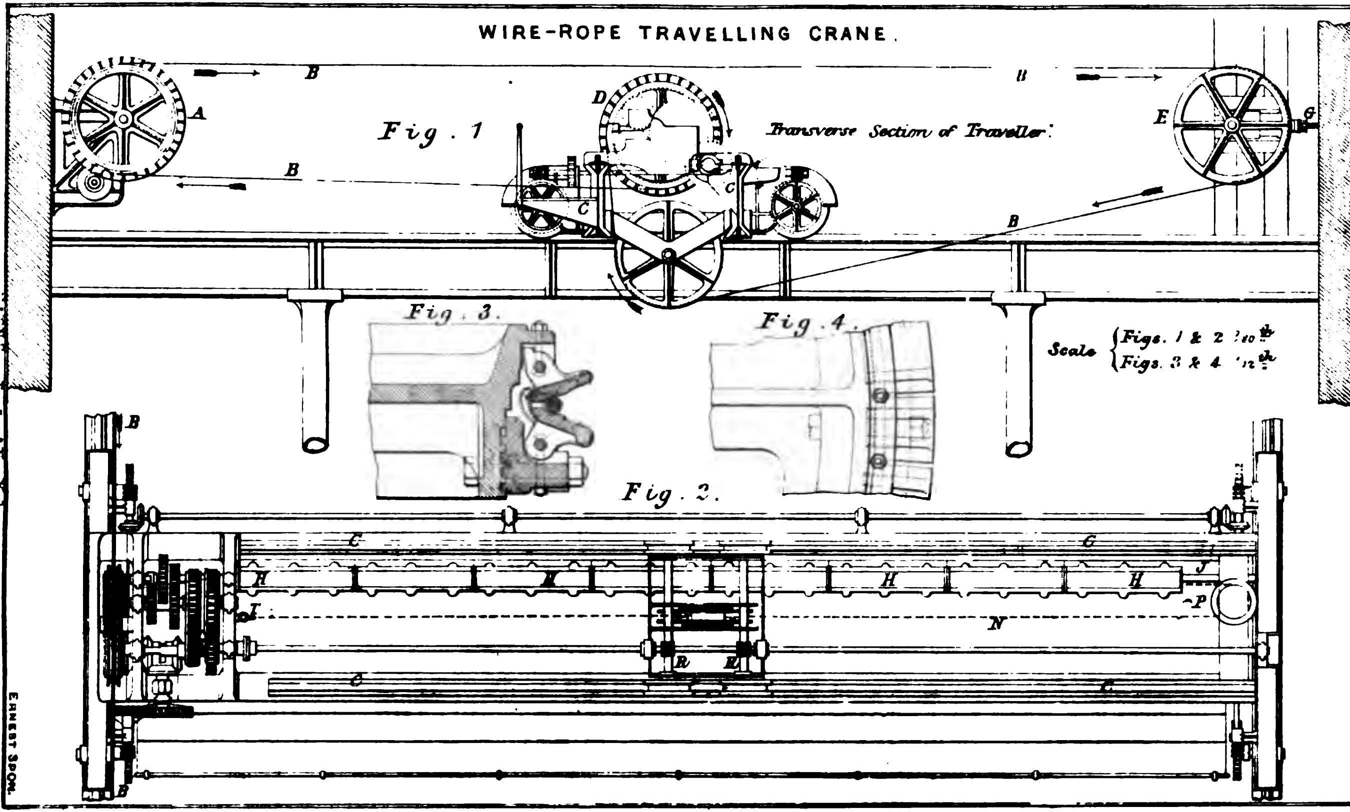
Scale; Figs. 1 & 2, 1/50th. Figs. 3 to 5, 1/12th.

ERNEST SPON.

E & F N Spon, London & New York.

Plate LXX.

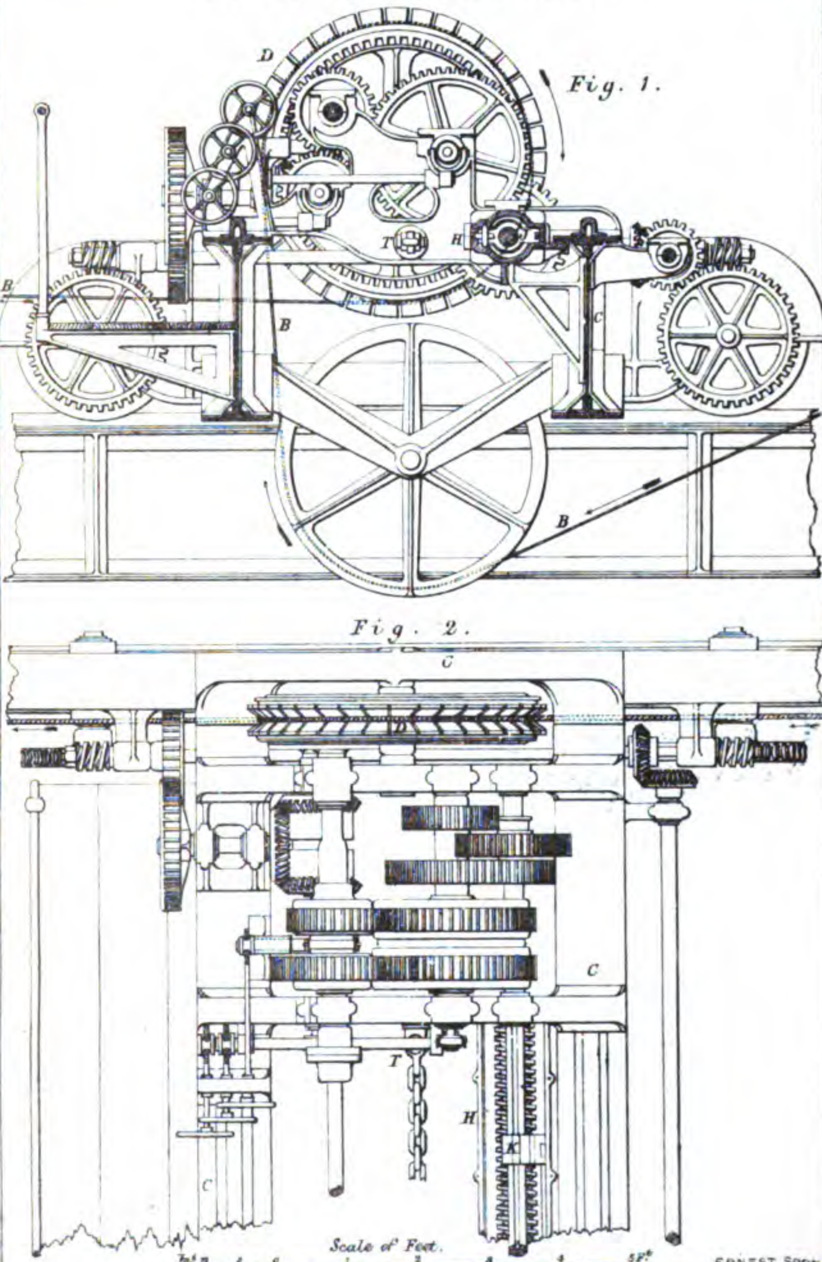
WIRE-ROPE TRAVELLING CRANE.



ERNEST SPON.

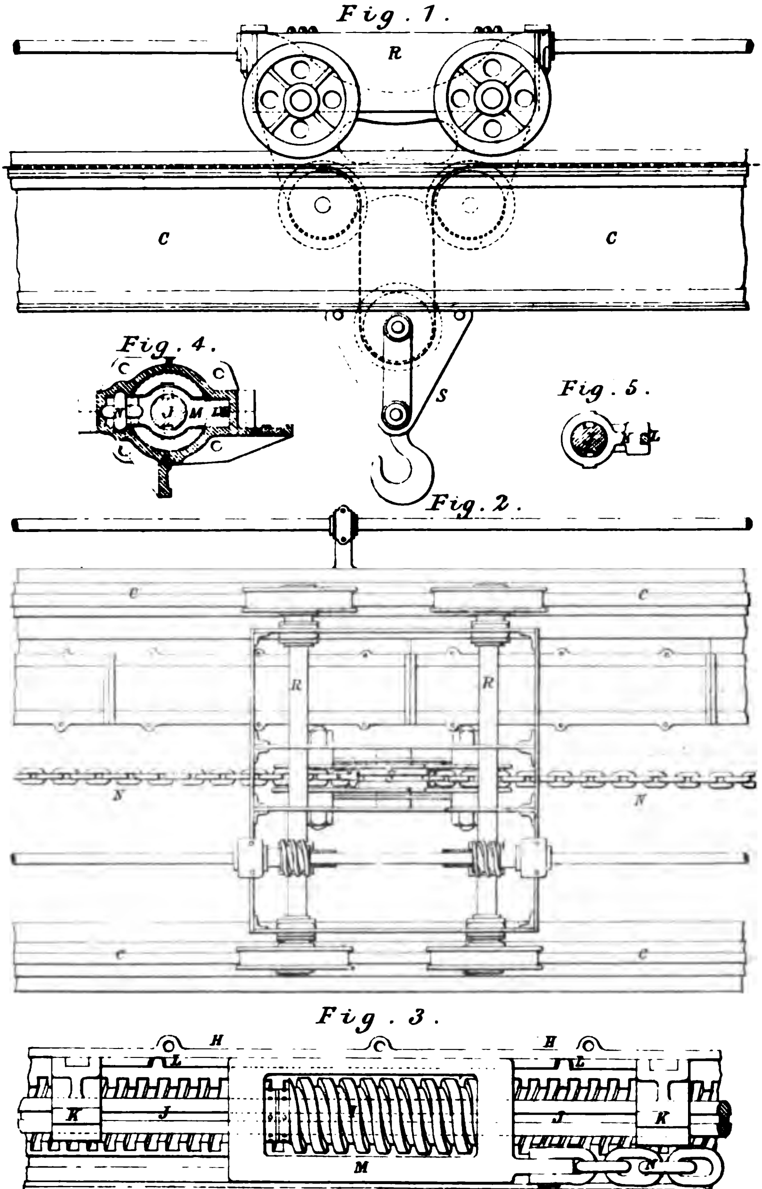
E. & F. N. Spon, London & New York

WIRE-ROPE TRAVELLING CRANE.



E. & F. N. Spon, London & New York

WIRE ROPE TRAVELLING CRANE.

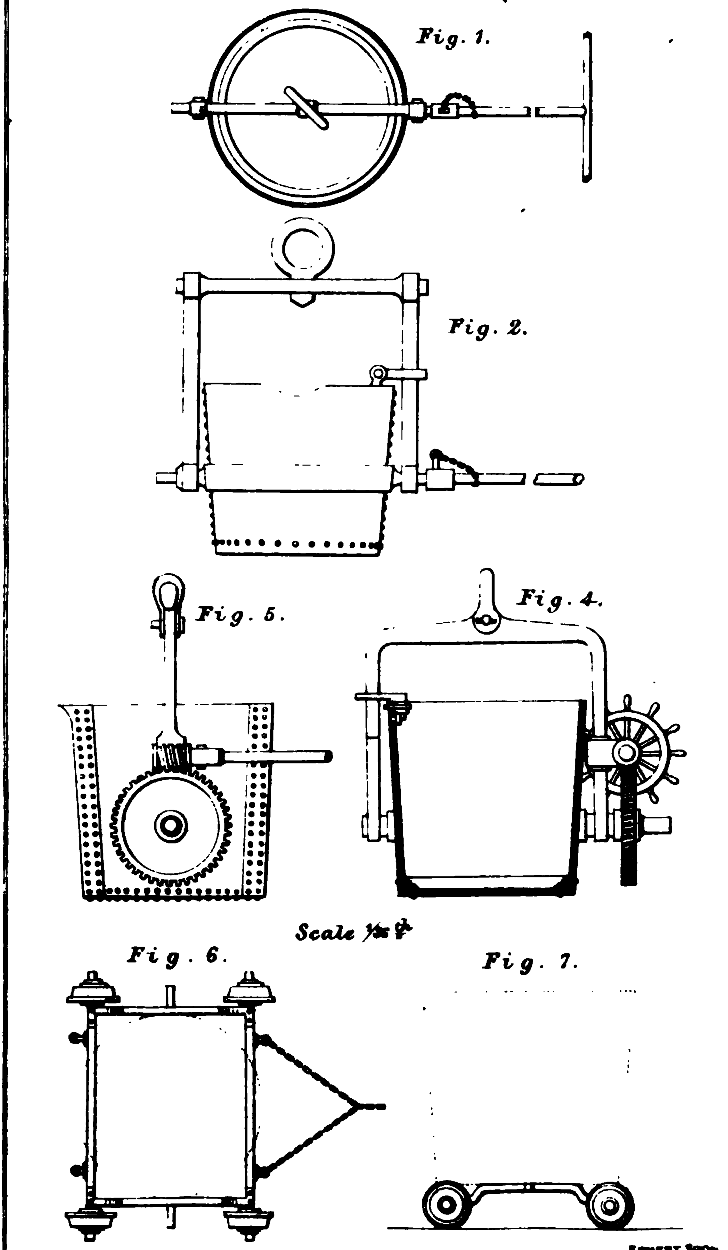


Scale; for Figs. 1 & 2, 1/32nd " . Figs. 3, 4 & 5, 1/16th " .

ERNEST SPON.

E & F.N. Spon. London & New York.

FOUNDRY LADLES.



E. & F. N. Spon London & New York

EMERY WHEELS.

Fig. 1.

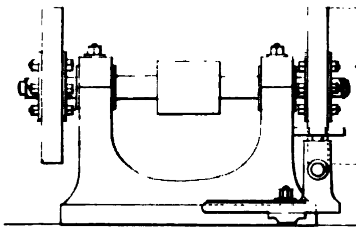
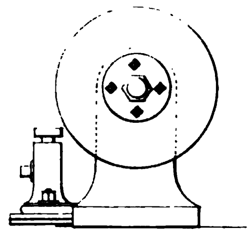


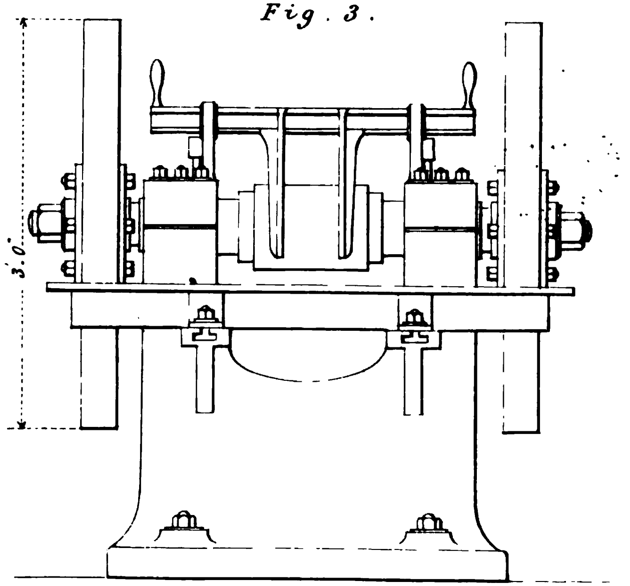
Fig. 2.



Scale Figs. 1 & 2, 1/14 th.

" Figs. 3 & 4, 1/17 th.

Fig. 3.



ERNEST SPON.

E & F. N. Spon. London & New York.

Plate LXXV

EMERY WHEEL.

Fig. 1.

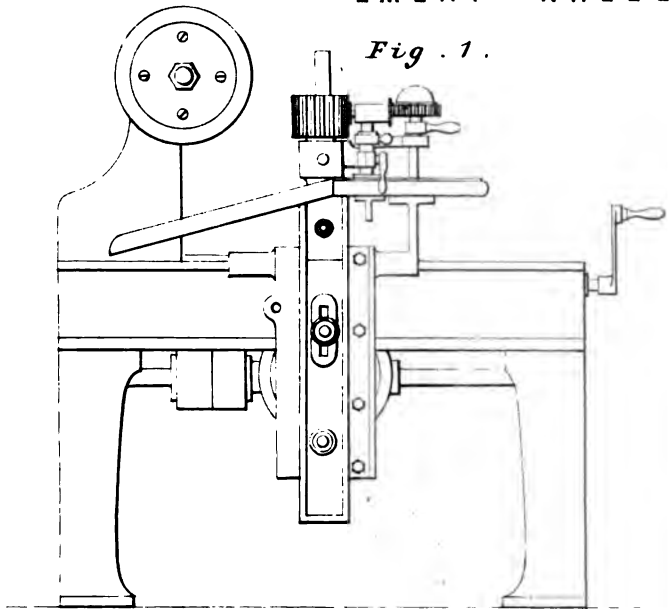
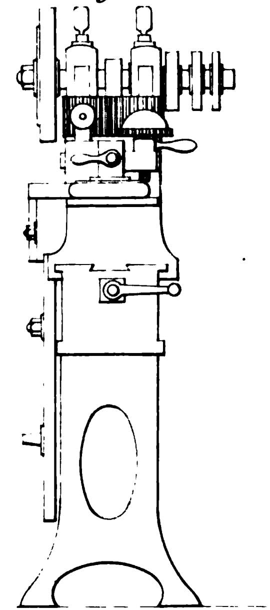


Fig. 2.



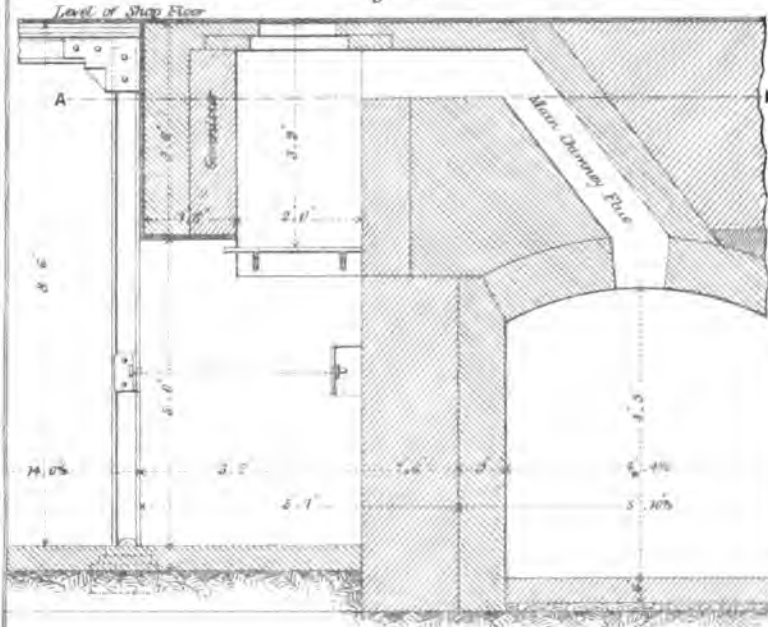
Scale, 1/18th.

ERNEST SPON.

E & F. N. Spon London & New York.

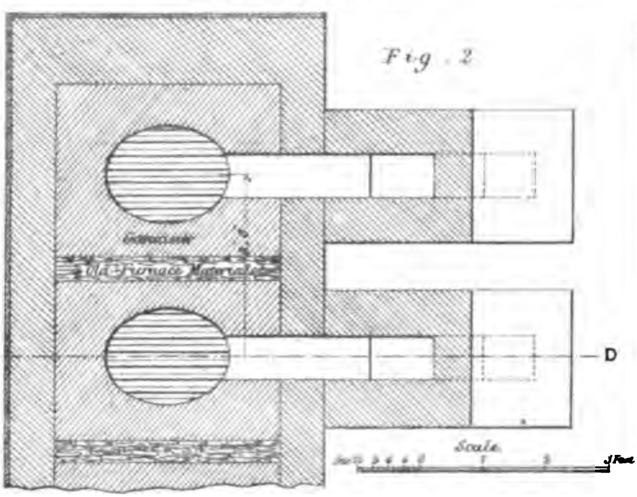
CRUCIBLE STEEL FURNACE.

Fig. 1.



Section at C.D.

Fig. 2



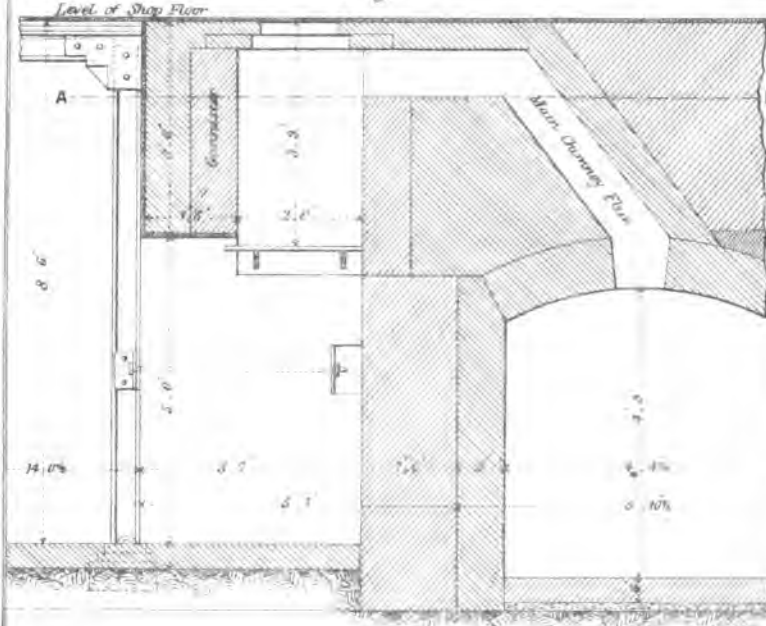
Plan at A.B.

ERNEST SPON.

E & F. N. Spon. London & New York

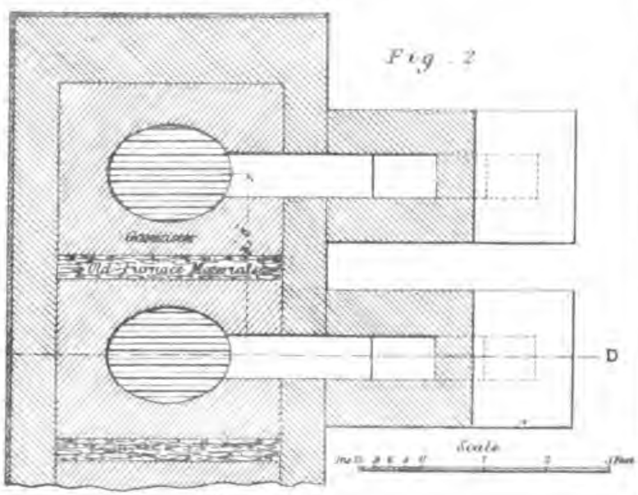
CRUCIBLE STEEL FURNACE.

Fig. 1.



Section at C D.

Fig. 2.



Plan at A B.

ERNEST SPON.

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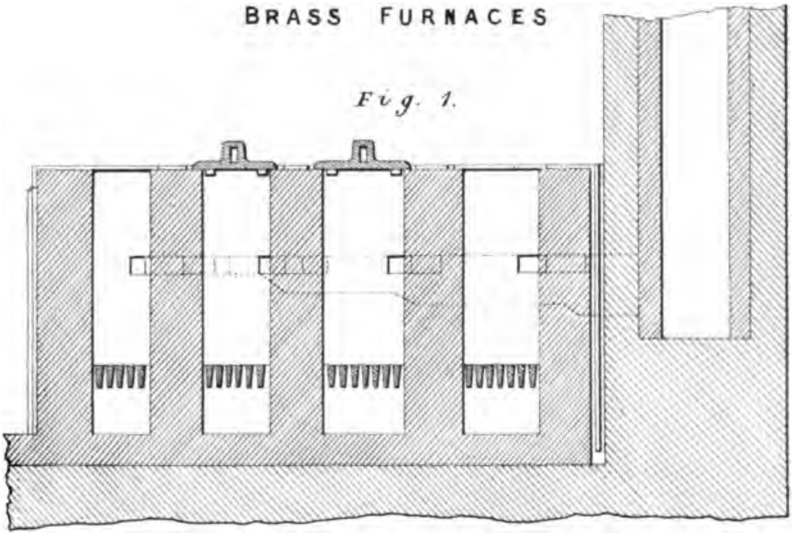
BRASS FURNACES

Fig. 1.



Sectional Elevation

Fig. 3.

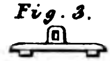
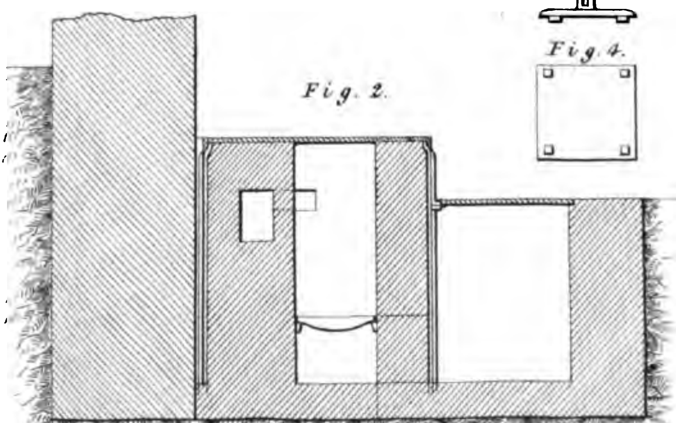


Fig. 4.

Fig. 2.



Section.

Scale.

Inches 12 — 0 — 1 — 2 — 3 — 4 — 5 Feet

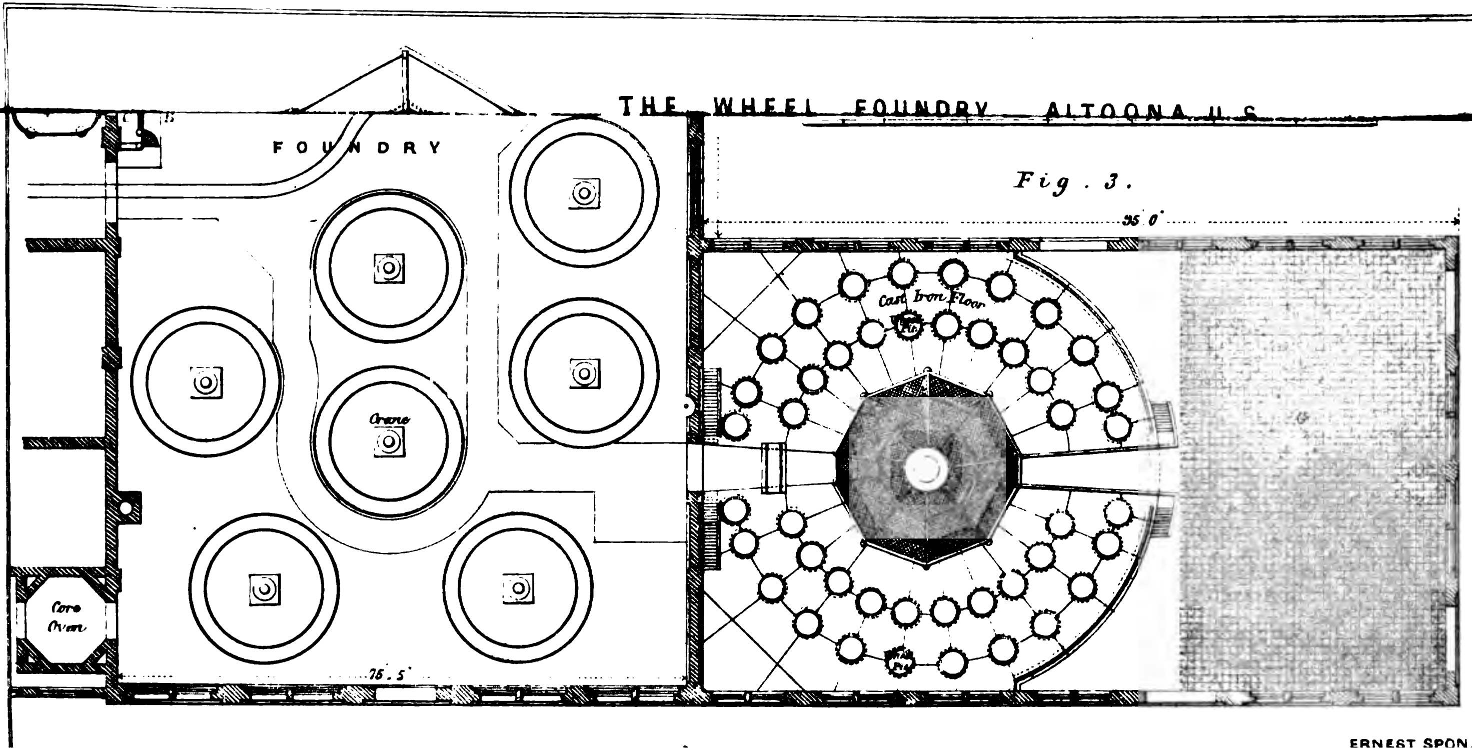
ERNEST SPON.

E.&F.N. Spon, London & New York.

Plate LXXI

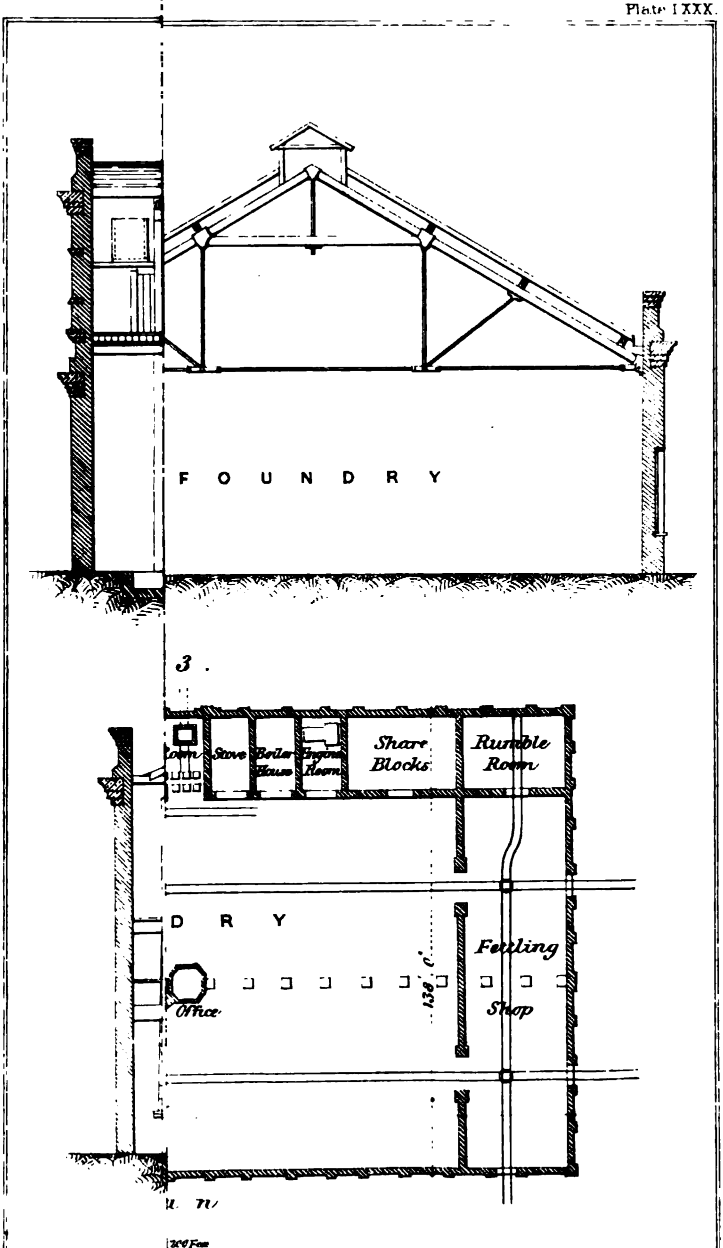
THE WHEEL FOUNDRY ALTOONA U.S.

Fig. 3.

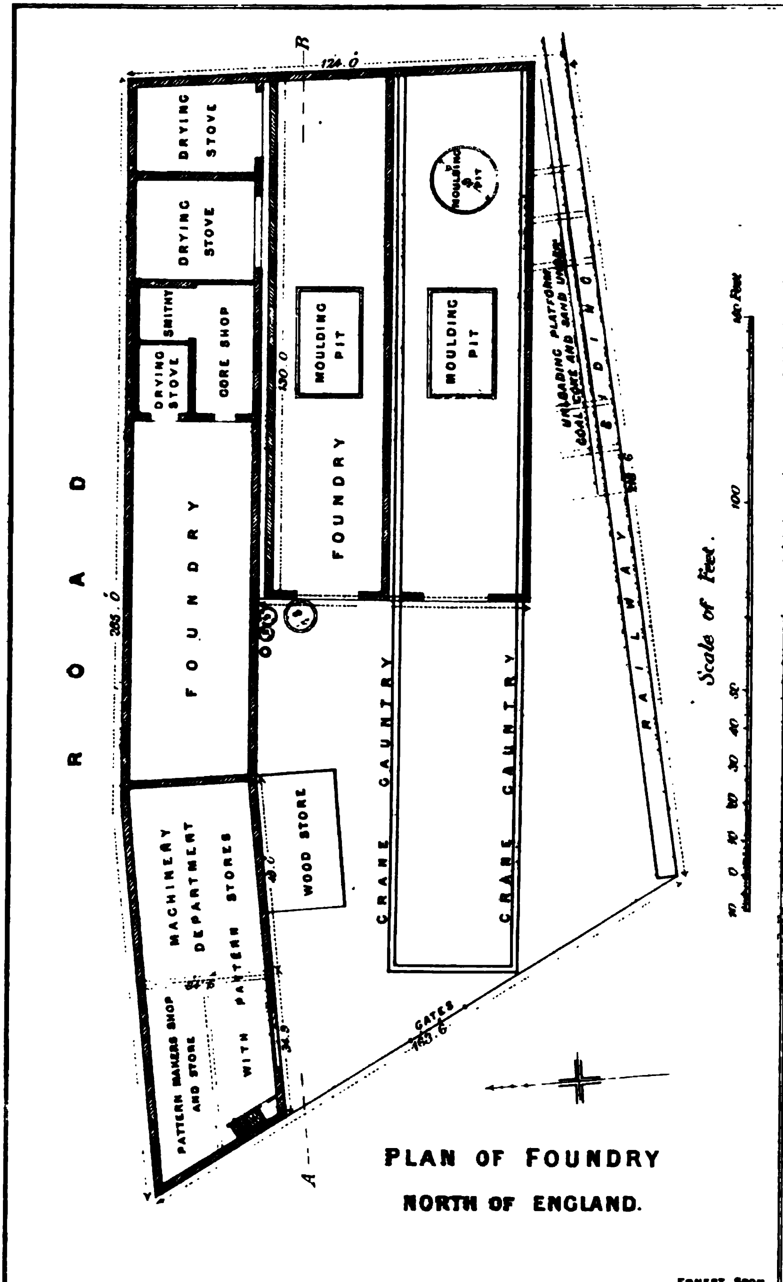


ERNEST SPON

Plate LXXX.



ERNEST SPON.



PLAN OF FOUNDRY

NORTH OF ENGLAND.

E. & F. N. Spon London & New York.

Plate LXXXII.

FOUNDRY – NORTH OF ENGLAND.

End Elevation

Section on Line A. B.

ERNEST SPON

E & F N Spon London & New York